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Spatial and Temporal Variation in Trophic Structure of the Nueces Marsh, TX

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Spatial and Temporal Variation in Trophic Structure of the Nueces Marsh, TX

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Dedication

This thesis is dedicated to my parents, Michael and Sumaya Wallace, for their years of love and support

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Abstract

Spatial and Temporal Variation in Trophic Structure of the Nueces Marsh, TX

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Salt marsh food webs are complex systems, with high levels of *in situ* primary production supporting a wealth of resident and migratory species. In this study, we use stable isotopes as a tool to trace organic matter utilization within the Nueces Marsh food web. Specifically, we were interested in (1) the use of treated wastewater as a ^{15}N tracer, and (2) seasonal and interannual variation in food web structure. We hypothesized that treated wastewater would selectively label detrital resourse use within the food web, allowing us to trace grazing vs. detrital pathways within the marsh system. We also hypothesized that marsh consumers would exhibit distinct differences in isotopic composition between summer and winter, and between different years. We found that the Nueces Marsh food web consists of 3.5 consumer trophic levels. The $\delta^{13}C$ values of consumer organisms were similar across the spatial extent of the low marsh, regardless of proximity to wastewater inflow. However, a majority of the organisms collected from the wastewater channel were significantly ($p<0.05$) enriched in ^{15}N compared to their reference counterparts. We propose that ^{15}N-enriched nitrogen is entering the Nueces Marsh food web through detrital rather than grazing-based pathways, making wastewater effluent an effective tracer of detrital integration into a marsh food web system.

Hydrologic data indicate that isotopic shifts between seasons and between years reflected larger scale shifts between drought and wet years. During drought years, decreased production by phytoplankton and emergent plants led consumers to rely more heavily on ^{13}C-enriched cyanobacterial carbon. In contrast, wet years encourage phytoplankton and emergent plant production, making cyanobacterial carbon relatively less exploited. While the Nueces Marsh food web is supported by a stable detrital carbon pool, it may still be susceptible to larger scale hydrologic events.

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ABSTRACT:

Salt marsh food webs are complex, relying on both *in situ* and imported primary production. We utilized natural abundance stable isotope techniques in concert with an ^{15}N-enriched wastewater end-member to explore trophic structure within the Nueces Marsh, TX. Specifically, we were interested in the use of treated wastewater as a ^{15}N tracer, hypothesizing that it would selectively label detrital resourse use within the food web. We compared the stable isotopic signatures of primary producers and consumers in a wastewater-influenced tidal creek (WW) to those in a reference channel (REF). We found that both wastewater and reference channels possessed similar trophic structures with 3.5 consumer trophic levels. The $\delta^{13}C$ values of consumer organisms were also similar between REF and WW sites. However, a majority of the organisms collected from the wastewater channel were significantly ($p<0.05$) enriched in ^{15}N compared to their reference counterparts. The exceptions to this pattern of enrichment were planktivorous organisms, which retained $\delta^{15}N$ values similar to the reference site. The higher consumer $\delta^{15}N$ values at the WW site was coincident with ^{15}N enrichment of emergent vegetation and cyanobacterial mat isotopic signatures. In contrast, POM pool showed limited ^{15}N enrichment between REF and WW. These data suggest that wastewater-derived, ^{15}N-enriched nitrogen is entering the Nueces Marsh food web through detrital rather than grazing-based pathways, making wastewater effluent an effective tracer of detrital integration into a marsh food web system.

INTRODUCTION

Coastal ecosystems possess some of the most economically and ecologically valuable habitats, and are among the most vulnerable. In the United States alone, over 50% of the population lives near the coast, a region comprising only 17% of the country's land area (Scavia et al. 2002). Further population growth is expected to concentrate in

this already developed area within the next 25 years, increasing the pressures from nutrient pollution, fragmentation, and resource exploitation on a multitude of coastal habitats (Scavia et al. 2002).

Estuaries are of particular concern, as they provide more human services than any other ecosystem (Costanza et al. 1997, Emeis et al. 2001). These services include supporting economically valuable industries such as fisheries, petroleum and mineral deposits, and recreation. Apart from these exploitative uses, coastal systems provide valuable services in the form of nutrient cycling, flood control, and water treatment (Scavia et al. 2002). In addition, the biological diversity contained within coastal ecosystems is of great ecological importance.

Various estuarine habitat types, such as salt marshes and mangroves, provide both structure and food resources for a multitude of vertebrate and invertebrate consumers (Boesch and Turner 1984, Abrantes and Sheaves 2009). Along the Gulf and Atlantic coasts of the United States, 70% of marine fishes depend on estuaries for at least a portion of their life history (Deegan 2002, Boesch and Turner 1984). The ability of estuaries to sustain such large and diverse consumer populations depends on the available organic matter pool and the stability of the trophic linkages between producers and consumers (Abrantes and Sheaves 2009).

Salt marshes are a predominant estuarine habitat along the Gulf and Atlantic coasts of the United States, and are found extensively throughout the globe (Roman et al. 2000). Comprised of open water and stands of emergent vegetation, these habitats provide both structure and food for a variety of resident and migratory species. Salt marsh food webs are notoriously complicated, due to the variety of potential organic matter sources (Deegan and Garritt 1997). The leading paradigm for several decades was that emergent vegetation and its associated detritus formed the base of the salt marsh food web, because of its overwhelming dominance in terms of biomass (Peterson and Howarth 1987). However, studies conducted in a multitude of marshes around the globe indicate that the degree to which various producers contribute to the food web is system-specific (Haines and Montague 1979, Peterson and Howarth 1987). The role of various autochthonous and allochthonous carbon sources, such as emergent vegetation, microphytobenthos, and phytoplankton in supporting consumer assemblages in salt

marshes is an essential question for understanding ecosystem function (Peterson and Howarth 1987).

Stable isotope ratios can be a useful tool in determining the fate of carbon from different autotrophic sources. Natural abundance stable isotope studies use the inherent variation in isotopic ratios from primary producers to differentiate between carbon sources (Fry 2006, Peterson and Howarth 1987, Mullholland et al. 2000). The isotopic variation results from primary producers using different photosynthetic pathways (C_3 vs. C_4) and the different sources of CO_2 (atmospheric vs. aqueous) (Fry 2006). Fractionation between trophic levels determines the trophic position of consumers relative to their ultimate carbon source.

The Nueces delta provides a unique environment in which to use stable isotopes to investigate trophic dynamics. The largest deltaic marsh in south Texas, the Nueces Marsh occupies approximately 5,850 ha along the upper reaches of Nueces Bay, a secondary bay within the Corpus Christi Bay system (Dunton and Hill 2006, Brock 2001). The Nueces River is the single freshwater tributary to the bay system. The delta itself is predominately salt marsh habitat, consisting of scattered low marsh *Spartina alterniflora* stands and high marsh succulents and herbaceous plants. Vegetated areas are interspersed with mudflats and open water. The delta supports a wide variety of vertebrate and invertebrate nekton species, including commercially important fin and shellfish, a host of infaunal and benthic invertebrate communities, and several species of migratory birds (Brusati et al. 2001, Dunton and Hill 2006, Fejes et al. 2005).

In this study, we use natural abundance stable isotope techniques to answer questions about the food web structure of the Nueces Marsh, Texas. This study takes advantage of the distinct ^{15}N signal of treated wastewater, which acts as an *in situ* tracer. This effluent is enriched in ^{15}N, due to the degree of biological processing and fractionation it undergoes during treatment (Fry 2006). Treated wastewater effluent is released from the Allison Wastewater Treatment Plant into a single tidal channel within the marsh.

Our objective in this study was to use natural abundance stable isotope techniques to elucidate trophic structure within the Nueces Marsh. Specifically, we were interested in determining the major carbon sources used by consumers. We hypothesized that the

Nueces Marsh depends on considerable input of both emergent vegetation detritus as well as autochthonous phytoplankton production. This results in the system possessing two largely independent pathways for energy to reach higher trophic levels.

Secondly, we aimed to determine the utility of treated wastewater as a tracer for detrital resources within the marsh system. We hypothesized that based on differential uptake of wastewater-DIN, the ^{15}N signal of wastewater would selectively label the benthic detrital pool, and that this ^{15}N signal would persist in detrital reliant consumers. A majority of the phytoplankton in the Nueces Marsh is advected, by either winds or tides, from Nueces and Corpus Christi Bays. This would result in the disparate ^{15}N signals between emergent vegetation and phytoplankton.

The use of a ^{15}N-enriched endmember in this study allows for greater specificity in differentiating between basal carbon resources (Peterson 2001). Estuarine food webs are complicated in that they possess many potential carbon sources and a diversity of consumers (Peterson et al. 1985, Akin and Winemiller 2006). These food webs exist within a highly variable physical environment, with drastic annual changes in salinity, nutrient delivery, and flow volume. By identifying the main carbon and nitrogen sources, and trophic energy pathways, we can better predict how changes in abiotic conditions, whether of natural or anthropogenic origin, will affect community resilience and ecosystem function.

METHODS

Study Area

We sampled along two channels in the lower Nueces Marsh, located approximately 20 km northwest of Corpus Christi, TX. Low river inputs, low precipitation, and high evaporation result in the classification of the Nueces as a reverse estuary, with salinities in the upper reaches of the delta higher than those in the bays (Dunton and Hill 2006). Dominant vegetation includes salt tolerant woody shrubs, succulents, and grasses. Predominant species include *Borrichia fructescens* (sea oxeye daisy), *Batis maritima* (saltwort), *Salicornia virginica* (glasswort), *Distichlis spicata* (saltgrass), and *Spartina alterniflora* (smooth cordgrass) (Alexander and Dunton 2006).

The Allison Wastewater Treatment Plant sits along the western fringes of the marsh, along the banks of the Nueces River. It processes approximately 3.5 dry tons of sludge per day, and discharges effluent with an average of 4.0 mg L^{-1} biological oxygen demand and 6.0 mg L^{-1} total suspended solids (City of Corpus Christi). Prior to 1998, effluent was discharged directly into the Nueces River. Following the implementation of the Allison Wastewater Treatment Plant Effluent Diversion Demonstration Project, ~7,570 m^3d^{-1} of effluent was diverted into the Nueces Marsh (Dunton and Hill 2006). Treated effluent is pumped into holding ponds, and flows into a natural tidal creek through connecting culverts.

Samples were collected from four sample sites along the tidal creek receiving effluent (WW 1-4) and three sites along an adjacent reference channel (REF 1-3) (Figure 1). Both tidal creeks were shallow (max. depth 2 m) with muddy bottoms and framed by vegetated banks. Samples were collected from sites WW2 and REF1 during summers 2002, 2003, 2006 and 2008. Samples from all seven sites were collected in summer 2009, winter 2010, and summer 2010. Individual sample sites were pooled at the conclusion of sampling into three larger study areas, with WW comprising sites WW1-3, with WW4 categorized separately as INT (intermediate) because of its location at the confluence of the wastewater channel with Nueces Bay. All three REF stations were pooled into one (REF).

Sample Collection and Processing

Water temperature, salinity, conductivity, dissolved oxygen (mg/L and % saturation), pH, and water depth were measured at each sample site using a YSI 600XLM data sonde (YSI Incorporated, Yellow Springs, OH). Additionally, 4 replicate surface water samples were taken in acid washed polypropylene bottles for analysis of water column NH_4^+ and NO_2+NO_3. Water samples were transported on ice back to the lab, diluted with ammonium-free seawater where necessary (3-5:1), and analyzed using standard colormetric techniques (Parsons et al. 1984).

At each site, representative samples of vertebrate and invertebrate nekton and benthic organisms were collected to construct a detailed food web. This approach included collecting replicate (N= 3 or 4) samples of emergent vegetation species, water

column particulate organic matter (POM), sediments, benthic cyanobacterial mats, drift macroalgae, epibenthic and infaunal invertebrates, zooplankton, and vertebrate and invertebrate nekton species. Emergent vegetation was hand-collected from new growth on plants growing within 0.5 m of the bank. POM was collected in prewashed polypropylene bottles and vacuum-filtered onto pre-weighed glass fiber filters. A 50 cc syringe core liner was used to collect surface sediments. Cyanobacteria were gently scraped from the surface of bank sediments. Bank sediments were sieved for polychaete worms and other infaunal organisms. Nekton samples were collected using replicate pulls of a 40-ft bag sein. All samples were transported on ice to the University of Texas Marine Science Institute for identification and isotopic analysis.

Isotopic Analysis

Animal, plant, and sediment samples were prepared for analysis of stable carbon and nitrogen isotopes. Vegetation samples were rinsed in distilled water to remove sediments and epiphytes, dried to a constant weight, and homogenized using mortar and pestle or Wig-L-Bug (Dentsply International). POM filters were dried, weighed, and divided into two subsamples, one of which was acidified in 10% HCl to remove calcareous material. Sediments were similarly divided into acidified and non-acidified subsamples. All subsamples were dried and homogenized. For a majority of animal samples, white mussle tissue was removed for analysis. Small fish, crabs, worms, and bivalves were prepared by removing the skin, carapace, or shell and digestive tracts before being sub-sampled to provide acidified and non-acidified samples.

Samples were run on a Finnigan MAT Delta Plus continuous flow Isotope Mass Spectrometer coupled with an elemental analyzer (NC 2500; Carlo Erba Instruments, Milan, Italy). Results for $\delta^{15}N$ and $\delta^{13}C$ are reported in reference to $R_{standard}$ of atmospheric N and Pee-Dee Belemnite, respectively. Values are reported in standard notation as:

$$\delta^{H}X\ (‰) = [(R_{sample}/R_{standard}) - 1] * 1000,$$

where R equals the ratio of heavy:light isotope within the sample or standard.

Statistics

We ran a one-way ANOVA on the various organic matter end member $\delta^{13}C$ values in order to determine whether they could be distinguished for tracing trophic relationships. The four end-members considered were C_3 emergent vegetation, C_4 emergent grasses, cyanobacteria, and particulate organic matter (POM). Consumer isotopic signatures were compared using a Student's t-test. All statistical analyses were performed using R, and significance levels were held constant at α=0.05.

RESULTS

Water chemistry

Sonde measurements of temperature, salinity, DO, and pH were similar between REF, INT, and WW sites. Seasonal differences were apparent in temperature and dissolved oxygen, with summer values of 32.4°C and 5.5 mg L^{-1} transitioning to winter values of 15.7°C and 10.9 mg L^{-1} . Salinity was much higher during summer 2009 than either winter or summer 2010 as a result of drought conditions (Table 1.1). The minor differences between sample sites suggest comparable physical and chemical environments.

Inorganic nitrogen concentrations varied greatly between sample sites (Table 1.2). Highest concentrations of both nitrate+nitrite (NO_3^-+NO_2^{2-}) and ammonium (NH_4^+) were observed at WW1, with concentrations of 188.3 μmol L^{-1} and 65.2 μmol L^{-1}, respectively. Concentrations of nitrate+nitrite decreased rapidly downstream of WW1, with concentrations dropping over 80% between WW1 and WW2 (from 188.3 μmol L^{-1} to 32.5 μmol L^{-1}), a distance of 460 m. Ammonium concentrations decreased more gradually, with a major reduction in concentration occurring between WW3 and INT.

Stable isotope composition

Primary producers:

We identified three isotopically distinct categories of primary producers: C_3 emergent plants, C_4 emergent plants, and cyanobacterial mats. (Tables 1.3 and 1.4). Three common C_3 plants (*Borrichia frutescens, Salicornia virginica, Batis maritima*) were most ^{13}C depleted, with a mean of -27.1‰. In contrast, the average $\delta^{13}C$ value of two

predominant C4 plant species was -14.1‰. Cyanobacterial mats had intermediate $\delta^{13}C$ values of -15.9‰. In addition to these three homogeneous groups, we identified an isotopically distinct particulate organic matter pool (POM) with a mean $\delta^{13}C$ signature of -22.6‰. POM was composed of primarily phytoplankton, but also contained emergent vegetation detrital matter. There were no significant site differences in the $\delta^{13}C$ values of plants collected at REF and WW stations (Student's t-test, p=0.98).

The $\delta^{15}N$ values of C_3 plants, C_4 plants, and POM from REF were similar, ranging from 2.9 and 5.8‰ (Table 1.3). Cyanobacterial mats possessed a distinctly lower $\delta^{15}N$ signal (0.3‰), reflective of their fixation of atmospheric nitrogen.

Primary producer $\delta^{15}N$ values were more variable within the wastewater channel. C_3 plants and C_4 plants were significantly enriched in ^{15}N, with values ranging from 5.9-10.2‰ (Student's t-test, $p<0.001$) (Table 1.4). There was also marked spatial variation in $\delta^{15}N$ values of emergent vegetation in the wastewater channel, with $\delta^{15}N$ values decreasing with distance from the effluent source (Figure 1.2). The $\delta^{15}N$ values of POM and cyanobacteria at WW were enriched slightly compared to REF at 5.7‰ and1.6‰, respectively.

Consumers:

A total of 39 different species of fish and invertebrates were collected over the three separate sampling efforts. Of these, 22 species were common to both WW and REF stations. These species were separated into one of four trophic guilds (planktivore, detritivore, zoobenthic carnivore, and piscivore) based on literature-based descriptions of diet.

The range in $\delta^{13}C$ values among species was similar between species collected at both REF and WW (Figure 1.3 and 1.4). Consumer $\delta^{13}C$ values spanned an overall range of -23.2 to -13.3‰. Consumers were not well separated by $\delta^{13}C$, with most consumers falling between -20 and -16‰ at both REF and WW. There were no significant differences ($p>0.05$) between $\delta^{13}C$ values of REF and WW individuals for any species, or between trophic guilds (Figure 1.3).

The $\delta^{15}N$ values of several consumers differed between the REF and WW sites. Values ranged from 7.3 to 14.4‰ at REF, and from 9.1 to 17.3‰ at WW. When

consumers were broken into trophic guilds, significant differences in $\delta^{15}N$ values occured between REF and WW for some organisms, while others were unaffected (Figures 1.5). Of the 22 species, all possessed elevated $\delta^{15}N$ values at WW, and 14 of the 22 have significantly ($p<0.05$) higher $\delta^{15}N$ values (Figure 1.5). The relative magnitude of the shift in $\delta^{15}N$ values between REF and WW varied by trophic guild. Values were significantly higher ($p<0.05$) for all detritivorous species collected at WW compared to REF, and a majority of the zoobenthic carnivores (Figure 1.5). However, 4 out of 5 planktivorous species showed no significant change ($p>0.05$) in $\delta^{15}N$. The exception was the tidewater silverside (*Menidia peninsulae*) ($p=0.03$), which has been observed to supplement is diet of zooplankton with phytodetritus (Lucas 1982). Of the three piscivorous species, two showed significantly higher $\delta^{15}N$ values at WW ($p=0.05$ and $p=0.001$), even though they are pelagic feeders (Figure 1.5).

Trophic structure

Isotope ^{13}C:^{15}N biplots of the primary producers and consumers common to both REF and WW sample sites revealed little difference in trophic structure between the two areas (Figures 1.3 and 1.4). Ranges in $\delta^{13}C$ values were similar between sites, indicating that consumers subsist on the same ultimate carbon sources, reinforcing previous observations. Of the four assigned trophic guilds, organisms grouped into the planktivore group showed the lowerst range of $\delta^{13}C$ values, with 5 of the 6 species occupying the -23 to -18‰ range (*Rangia* was notably heavier at -13.3‰)(Figure 1.6). This signal indicates that these benthic clams assimilate a ^{13}C replete carbon source, such as cyanobacteria or C_4 detritus. The other trophic guilds possessed wider $\delta^{13}C$ ranges, and in general, $\delta^{13}C$ was not helpful in distinguishing trophic pathways due to the degree of overlap between consumers. However, all organisms fell within the expected enrichment ranges of the most depleted and most enriched carbon source, suggesting that the primary producers collected represent plausible end members for both REF and WW food webs (Figures 1.3 and 1.4).

Previous studies have found negative correlations between organism $\delta^{13}C$ values and their C:N ratio (Rau et al. 1991). To ensure that shifts in $\delta^{13}C$ were valid for tracing dietary shifts, and not an artifact of substantial ^{13}C depleted lipid contributions, I

examined the relationship between $\delta^{13}C$ and C:N ratio. No relationship was found (R^2=0.15) (Figure 1.6).

DISCUSSION

Trophic structure

The range in $\delta^{15}N$ values of Nueces Marsh consumers indicates a food web comprised of 3.5 to 4 trophic levels (with primary producers as trophic level 1), with a majority of consumers occupying low (2.5-3) trophic positions (Table 1.5). Previous studies on trophic structure in South Texas salt marshes found similar results, but based on gut content rather than stable isotopes (Akin and Winemiller 2006, Fejes et al. 2005).

To calculate trophic levels (TL) for various marsh fauna, we first attempted to use their $\delta^{13}C$ values to determine their relative dependency on pelagic/POM and benthic/detrital resources. However, the combination of C_3 and C_4 vegetation within the detrital pool produces a $\delta^{13}C$ signature close to that of POM. Thus, faunal $\delta^{13}C$ values were supplemented with literature based information about diet to ascertain their reliance on various carbon resources.

We calculated a fractionation factor for $\delta^{15}N$ values between trophic levels by subtracting the average $\delta^{15}N$ of POM at REF and WW (3.4 and 5.7‰) from that of zooplankton (7.3 and 9.5‰). We calculated a fractionation factor between detritus (mean C_3 and C_4 $\delta^{15}N$ values) and sheepshead minnow (*Cyprinodon variegatus*, 8.4‰) at REF. These pathways produced a trophic fractionation factor of 3.8 and 3.5‰, respectively. These values both fall at the upper end of the range of reported $\delta^{15}N$ fractionation between trophic levels in other literature (Deegan and Garritt 1997, Vander Zanden and Rasmussen 2001). Slight over-estimation of trophic fractionation can result from both microbial respiration of detrital pool, and from consumer selectivity for particular portions of the POM pool (McCutchan et al. 2003, Mill et al. 2007).

Consumer organisms occupied predictable trophic levels expected from literature based diet studies. The top consumer, and the only organism to occupy the 4th trophic level, was the hardhead catfish (*Ariopsis felis*), which is a documented consumer of clams, fish, and crabs (Motta et al. 1995). Juvenile spotted seatrout (*Cynoscion nebulosus*) and red drum (*Sciaenops ocellatus*), which feed on smaller fish and

zooplankton, as well as zooplankton-dependent anchovy (*Anchoa mitchilli*) and menhaden (*Brevoortia patronus*) occupied the higher end of the third trophic level (McMichael and Peters 1989, McMichael and Peters 1987, DeLancey 1989, Castillo-Rivera et al. 1996). A majority of consumers occupied the 2nd and lower 3rd trophic levels, which aligns with the prediction that a majority of marsh consumers rely on detrital plant matter and small invertebrates (Darnell 1961).

Consumers were divided into trophic guilds based on literature-reported diets. These guilds were constructed to see if organisms of similar feeding modes shared similar stable isotopic signatures, and whether these guilds were isotopically distinct from each other. Overall, consumers within the Nueces Marsh exhibited a narrow range of $\delta^{13}C$ values. The $\delta^{13}C$ signatures of organisms from different trophic guilds overlapped considerably, reflecting the high degree of omnivory and opportunistic feeding present in salt marsh food webs (Figure 1.7) (Darnell 1961). Consumers from different trophic guilds also overlapped considerably in $\delta^{15}N$ values (Figure 1.8). Studies from other estuarine food webs have often reported high separation between organisms of different feeding guilds, but these systems may have higher degrees of import from adjacent environments, such as seagrass beds and mangroves (Abrantes and Sheaves 2009).

Planktivores behaved somewhat differently than all other feeding guilds. The $\delta^{13}C$ values of planktivorous species overlapped with the other trophic guilds, but as a group they showed no enrichment in ^{15}N between REF and WW sites. (Figure 1.8). This is consistant with the limited ^{15}N enrichment observed in the POM pool at WW(Tables 1.3 and 1.4). Our data shows that the WW ^{15}N signature is attenuated in the pelagic POM pool as a result of the high proportion of advected phytoplankton and organic matter. Consequently, POM-reliant consumers are not assimilating the wastewater ^{15}N signal. In contrast, the majority of zoobenthic carnivores, detritivores, and piscivores showed enrichment in ^{15}N between REF and WW sites. These consumers are likely more dependent on benthic, detrital carbon from emergent vegetation, which carries the enriched $\delta^{15}N$ signature. The difference ^{15}N enrichment between POM and emergent plants at the WW sites permitted us to use wastewater nitrogen as a tracer to help delineate the importance of detrital vs. grazing based trophic pathways within the Nueces Marsh system.

Wastewater influence in the Nueces Marsh

Differential $\delta^{15}N$ signatures of primary producers indicate that the treated wastewater nitrogen pool provides a useful tracer of detrital resource use, but only within a limited spatial scope. The rapid assimilation of wastewater nitrogen is apparent from both inorganic nutrient concentrations and emergent vegetation $\delta^{15}N$ signatures. Both NH_4^+ and $NO_3^- + NO_2^{2-}$ levels in the WW channel reached concentrations equivalent to REF within 4 km of wastewater discharge. The $\delta^{15}N$ values of INT emergent vegetation were not significantly different ($p>0.05$) from those at REF. These results indicate that producers effectively removed the additional nitrogen introduced from wastewater effluent from the water column before it can reach Nueces Bay.

Primary producers showed differential assimilation of wastewater nitrogen, as evidenced by the varying degrees of enrichment between REF and WW samples. Emergent vegetation (C_3 and C_4) exhibited an average increase in $\delta^{15}N$ values of 4.4‰ between WW and REF, with POM increasing by 2.3‰. Cyanobacteria at WW possessed a $\delta^{15}N$ signature of 1.6‰, which represents a five-fold increase over its REF $\delta^{15}N$ value of 0.3. The dramatic ^{15}N enrichment of WW cyanobacterial mats was unexpected, as cyanobacteria generally rely on N_2 as their primary nitrogen source. However, the cyanobacterial mats typical of Gulf coast salt marshes contain a variety of cyanobacterial species in addition to their associated benthic algae and heterotrophic bacteria (Bautista and Paerl 1985). While some cyanobacterial species can use NO_3^-, it seems likely that the enriched ^{15}N signal comes from the microalgae and associated bacteria that populate the cyanobacterial mats (Bautista and Paerl 1985, Bauersachs et al. 2009). Emergent vegetation and cyanobacterial mats may show a more dramatic change in $\delta^{15}N$ because of their stationary nature within the WW channel. The POM pool within the Nueces delta is very transient, consisting of both local production as well as wind and tide advected production. Thus, POM may not possess a $\delta^{15}N$ signature that is reflective of *in situ* production. In contrast, emergent vegetation and cyanobacteria integrate predominantly the local $\delta^{15}N$ signature, which at WW is influenced by ^{15}N-enriched wastewater DIN.

After accounting for the shift in $\delta^{15}N$ values of primary producers, most consumers showed no change in trophic position between REF and WW. The exceptions were the hardhead catfish (*Ariopsis felis*), red drum (*Scianops ocellatus*), gulf killifish

(*Fundulus grandis*), longnose killifish (*Fundulus similis*), and the violet goby (*Gobioides broussonnetii*). The hardhead catfish occupied the highest trophic level (4.1) at REF, but decreased to trophic level 3 at WW. In contrast, the red drum moved from trophic level 3 at REF to the top consumer at WW. The other three species shifted between trophic level 3 and 2. In actuality, the observed trophic shifts are likely an artifact of omnivory in these benthic consumers, which likely occupy an intermediate trophic level at both sites (Darnell 1961). This suggests that the introduction of treated wastewater to the Nueces Marsh causes a shifting $\delta^{15}N$ baseline for consumers, but is not actually altering trophic structure or linkages.

Trophic pathways

Despite literature based distinctions on feeding styles and resource preferences, isotopic signatures of consumers within the Nueces Marsh did not separate based on trophic guilds. Overlapping $\delta^{13}C$ values and consistent $\delta^{15}N$ enrichment between REF and WW sites indicate the reliance of Nueces Marsh consumers on benthic detrital resources. Planktivore consumers did not show the same divergence in $\delta^{15}N$ values between REF and WW sites, indicating that there may be some partitioning between pelagic, POM based resources and the benthic detrital pool.

Overall, the isotopic signatures of Nueces Marsh consumers indicate that emergent vegetation is an important carbon resource (Figure 1.9). Higher trophic level organisms with pelagic feeding modes, such as juvenile spotted sea trout (*Cynoscion nebulosus*) and red drum (*Scianops ocellatus*) have $\delta^{15}N$ values that suggest integration of detrital resources.

This assimilation of detrital, and ultimately emergent plant based carbon is key in understanding the role of *in situ* emergent production on salt marsh communities. Many studies have looked at the role of emergent vegetation as both a carbon source and structural subsidy within marshes (Haines and Montague 1979, Peterson et al. 1980, Currin et al. 1995). In particular, the applicability of the "outwelling hypothesis," (Haines 1977), where macrophyte derived carbon supports offshore foodwebs through DOC export and consumer migration, is commonly examined. The degree to which emergent plants support secondary production with marshes and in adjacent areas appears

variable and highly system specific (Melville and Connolly 2005, Boesch and Turner 1984, Peterson and Howarth 1987, Howe and Simenstad 2011). Based on the stable isotopic signatures of consumers within the Nueces Marsh, emergent vegetation assumes an integral role in supporting secondary production within the marsh itself. While the export of detrital carbon through water exchange was not measured, it is certainly exported through the movement of migratory consumer species that utilize the marsh for limited portions of their life history (Boesch and Turner 1984, Akin and Winemiller 2006). This implies that the emergent production of the Nueces Marsh an important basal resource in both local estuarine and nearby coastal food web systems.

Chapter 2 – Temporal variation in trophic structure of the Nueces Marsh, TX

Abstract:

Salt marsh food webs rely on organic matter from several sources, with terrestrial, freshwater, and marine input supplementing *in situ* production. Temporal variation in environmental conditions may change the prevalence or importance of these sources to estuarine consumers. We examined the relative importance of various organic carbon sources in the Nueces Marsh, TX, by comparing consumer isotopic signatures across multiple summers (2002-2010) as well as between consecutive summer and winter seasons (2009-2010). We hypothesized organisms would show distinct differences in isotopic composition between summer and winter, and between different summer seasons. Stable carbon and nitrogen isotopic measurements of primary producer and consumers common to all years were analyzed using circular statistics to examine net community changes between seasons. Consumers displayed a significant shift in $\delta^{13}C$ values between pooled summers and winter 2010. We found a significant seasonal shift from summer 2009 to winter 2010, with organisms becoming more depleted in ^{13}C and slightly enriched in ^{15}N in the winter. However, a corresponding rebound in isotopic composition was not observed from winter 2010 to summer 2010. Hydrologic data indicate that isotopic shifts reflected larger scale shifts between drought and wet years. During drought years, decreased production by phytoplankton and emergent plants led consumers to rely more heavily on ^{13}C-enriched cyanobacterial carbon. In contrast, wet years encourage phytoplankton and emergent plant production, making cyanobacterial carbon relatively less exploited. These data suggest that interannual variation in hydrologic regime may influence trophic structure, even in relatively stable detrital based ecosystems.

INTRODUCTION

Salt marsh food webs are notoriously complex, largely because of the variety of autotrophs available as food sources (Peterson et al. 1985, Deegan and Garritt 1997). Terrestrial, riverine, and marine habitats all export organic matter to estuarine systems,

and marshes receive considerable amounts of organic material from emergent vegetation, phytoplankton, and benthic microalgae (Odum 1988, Peterson et al. 1985, Deegan and Garritt 1997).

Emergent vegetation detritus was long thought to be the primary source of organic carbon to salt marsh food webs, in part because of its prevalence and structural importance (Peterson and Howarth 1987). However, stable carbon isotope analyses indicated that in some cases phytoplankton and microphytobenthos were equally if not more important, especially for filter-feeding consumers (Haines and Montague 1979). Further studies indicated that the primary source of carbon varied significantly by location (Peterson et al. 1980, Peterson and Howarth 1987, Stribling and Cornwell 1997).

The importance of various organic matter sources to estuarine consumers is further complicated by temporal variation in environmental conditions which affect the production or delivery of organic matter. Variation in temperature, precipitation, and water residence time all have cascading effects on the availability of organic matter to consumers. Studies on stream communities found that consumers switched from autochthonous to allochthonous resources based on seasonal shifts in the abundance of algal or planktonic production (Dekar et al. 2009, Reid et al. 2008). In addition, seasonal flow dynamics within riverine communities were found to greatly affects the basal carbon source to consumers (Zeug and Winemiller 2008).

Compared to freshwater systems, seasonal food web dynamics remain relatively unexplored in estuaries (Vizzini and Mazzola 2003). Although salt marsh food webs are buffered by a large pool of detrital material, they are still subject to seasonal changes in temperature, freshwater inflow, and primary production that may lead to shifting basal resource use by consumer species (Vizzini and Mazzola 2003, Akin and Winemiller 2006, Odum 1988). In addition, the diversity of trophic guilds within a salt marsh community means that seasonal resource shifts may occur in some, but not all, trophic pathways (Akin and Winemiller 2006).

In this study, we use stable isotopic analysis of C and N to investigate seasonal and interannual variability in the trophic structure of the Nueces Marsh, Texas. Stable isotope analysis is a powerful tool for differentiating ultimate carbon sources in food webs. Differences in the CO_2 source for photosynthesis (aquatic vs. atmospheric) as well

as the mechanisms of photosynthesis (C_3 vs. C_4 pathways) results in classes of primary producers that possess distinct carbon isotope signatures (Fry 2006). These carbon signatures fractionate very little during consumption, allowing the basal carbon signature to transfer throught the food web. Stable nitrogen isotopes can occasionally be used to differentiate between organic matter sources, but are more commonly used as a measure of trophic position due to their fairly consistent fractionation between trophic levels (Vander Zanden and Rasmussen 2001, Fry 2006).

Previous studies on seasonal variation in salt marsh food webs have focused primarily on how changes in consumer assemblages affect trophic structure (Akin and Winemiller 2006). In addition, many previous studies focused on subsections of the community (e.g. the benthos), or on particular trophic pathways linked to economically valuable species (Gleason and Wellington 1988, Fejes et al. 2005, Montagna et al. 2002, Akin and Winemiller 2006). To our knowledge, previous studies have not used stable isotopes to investigate whole community trophic responses on a seasonal or interannual scale along the Texas coast.

This study investigates how utilization of basal resources changes on a seasonal basis, and the impact of these changes on trophic structure. We use circular statistics in order to quantitatively examine changes may have on a community-wide scale (Schmidt et al. 2007). Our specific questions for this study included, (1) whether the source of organic matter used by estuarine consumers varied seasonally, and if so, (2) were the seasonal changes seasonal isolated to a particular trophic pathways, or incorporated across the entire food web.

We hypothesized that estuarine consumers might rely more heavily on detrital carbon sources during the winter, when phytoplankton production is low. Consequently, any seasonal shift in consumer diet would be most apparent in filter feeding taxa as compared to benthic consumers that derive a substantial fraction of their nutrition from detrital sources.

METHODS

Study area

Sampling took place in the lower Nueces Marsh, which is part of the Nueces estuary, located approximately 20 km northwest of Corpus Christi, TX. The Nueces delta occupies the upper reaches of Nueces Bay, a secondary bay within the Corpus Christi Bay system (Dunton and Hill 2006, Brock 2001). The Nueces River is the major freshwater tributary into the estuary, however, river channelization has rerouted flow directly into Nueces Bay (Dunton et al. 2001). The system is characterized by flashy hydrology related to periodic high flows, but typically freshwater inflows are low and water residence time is high (0.46 yr) (Brock 2001). The semi-arid, subtropical climate of the Texas coastal bend means that the delta experiences humid, hot summers (average highs 33°C) and dry, mild winters (average low 8°C) (Ruth 1990, Dunton et al. 2001). Evaporation is high, and the delta generally experiences a net annual moisture loss (Dunton and Hill 2006).

The delta is composed of salt marsh habitat, mudflats, and open water. Dominant emergent plant species include *Borrichia fructescens* (sea oxeye daisy), *Batis maritima* (saltwort), *Salicornia virginica* (glasswort), *Distichlis spicata* (saltgrass), and *Spartina alterniflora* (smooth cordgrass) (Alexander and Dunton 2006).

Samples were collected from two pre-established sites (450 and 451) along the Rincon Bayou tidal creek in the lower Nueces Marsh (Figure 2.1). Both sites were shallow (< 2m), muddy-bottomed, and surrounded by emergent vegetation. Samples were collected during summer 2002, 2003, 2006, 2008, 2009, and 2010, and during winter 2010. Summer samples from 2002-2008 were collected in July, while summer 2009 samples were pooled from June and August collections. Summer 2010 samples were collected in August. Winter samples were pooled from February and March 2010.

Sample Collection and Processing

Water temperature, salinity, conductivity, dissolved oxygen (mg L^{-1} and % saturation), pH, and water depth were measured at each sample site using a YSI 600XLM data sonde (YSI Incorporated, Yellow Springs, OH). Additionally, 4 replicate surface water samples were taken in acid washed polypropylene bottles for analysis of water

column NH_4^+ and NO_2+NO_3. Water samples were transported on ice back to the lab, diluted with ammonium-free seawater where necessary (3-5:1), and analyzed using standard colormetric techniques (Parsons et al. 1984).

At each site, we collected representative samples of vertebrate and invertebrate nekton and benthic organisms. This included collecting replicate (n= 3 or 4) samples of all emergent vegetation species, water column particulate organic matter (POM), sediments, benthic cyanobacterial mats, drift macroalgae, epibenthic and infaunal invertebrates, zooplankton, and vertebrate and invertebrate nekton species. Emergent vegetation was hand-collected from new growth on plants growing within 0.5 m of the bank. POM was collected in prewashed polypropylene bottles and vacuum-filtered onto pre-weighed glass fiber filters. A 50 cc syringe core liner was used to collect the top 2 cm of sediments. Cyanobacteria were gently scraped from the surface of bank sediments. Bank sediments were sieved for polychaete worms and other infaunal organisms. Nekton samples were collected using replicate pulls of a 40-ft bag sein. All samples were transported on ice to the University of Texas Marine Science Institute for identification and isotopic analysis.

Isotopic Analysis

Animal, plant, and sediment samples were prepared for $\delta^{15}N$ and $\delta^{13}C$ analysis following Dunton (2000). Vegetation samples were rinsed in distilled water to remove sediments and epiphytes, dried to a constant weight, and homogenized using mortar and pestle or Wig-L-Bug (Company name, location). POM filters were dried, weighed, and divided into two subsamples, one of which was acidified in 10% HCl to remove calcareous material. Sediments were similarly divided into acidified and non-acidified subsamples. All subsamples were dried and homogenized. For animal specimens, white muscle sample was extracted, dried, and homogenized when possible. When organism size prevented this, whole organisms were prepared by removing the skin and digestive tracts before being sub-sampled to provide acidified and non-acidified samples.

Samples were run on a Finnigan MAT Delta Plus continuous flow Isotope Mass Spectrometer coupled with an elemental analyzer (NC 2500; Carlo Erba Instruments, Milan, Italy). Results for $\delta^{15}N$ and $\delta^{13}C$ are reported in reference to $R_{standard}$ of

atmospheric N and Pee-Dee Belemnite, respectively. Values are reported in standard notation as:

$\delta^{H}X$ (‰) = $[(R_{sample}/R_{standard}) - 1] * 1000$,

where R equals the ratio of heavy:light isotope within the sample or standard.

Statistical Analysis

We ran a one-way pairwise ANOVA test on the various primary producer end member $\delta^{13}C$ values in order to determine whether they could be distinguished from each other and to test for any seasonal differences in isotopic signatures. If significant differences were observed between seasons, this shift would need to be included in the baseline distribution before performing additional circular statistical analyses. Seasonal differences in isotopic signatures for individual species were evaluated using a Student's t-test. Summer consumer $\delta^{13}C$ values were compared using a one-way ANOVA to determine if any significant differences occurred between different summer seasons. Significance levels were held constant for both ANOVA and t-tests at α=0.05.

To quantify directional shifts in stable isotope composition ($^{13}C/^{15}N$) of the estuarine community, we applied circular statistics to consumer isotope values along a temporal gradient (Schmidt et al. 2007, Dekar et al. 2009). Circular statistics can be used to quantify shifts in community isotope composition across space and time by measuring the direction (angle) and distance between average isotope values between time points and sites. I fit a von Mises distribution to our sample of angles and calculated maximum likelihood estimates for the corresponding population parameters (Batschelet 1981). The sample angles were used to calculate a mean vector of change, with mean angle μ and length r. The length signifies the concentration of the angles, or the level of dispersion. A length of 0 indicates no concentration, while 1 indicates maximum concentration. Mean vectors were graphed using arrow diagrams, and Rayleigh's test for circular uniformity to determine if the sample of angles differed from random, or had directedness.

RESULTS

Ultimate carbon sources and estuarine consumers

Sampling efforts conducted from 2002 to 2010 resulted in the collection of between 8-22 unique species per season. Of these, five primary producer and seven consumer species were present during both winter 2010 and at least one summer (Table 2.1 and 2.2).

We identified three classes of primary producer carbon sources that are distinguishable by isotopic composition: C_3 emergent plants, C_4 emergent plants, and cyanobacterial mats. In addition to these homogeneous sources, we also identified an isotopically distinct particulate organic matter (POM) pool, comprised of a mixture of emergent vegetation detritus and phytoplankton. All consumer organisms collected during summer and winter sampling efforts had $\delta^{13}C$ values that fell between the most depleted and most enriched ultimate carbon sources, indicating that no important carbon sources were overlooked (Table 2.1; Figure 2.2).

Temporal trends in stable isotopic composition

Primary producers showed no significant change in $\delta^{13}C$ any of the sampling seasons ($p=0.88$). Primary producers did exhibit seasonal shifts in $\delta^{15}N$, with summer 2010 significantly different from both summer 2009 and winter 2010 ($p=0.003$ and 0.006, respectively). These shifts in basal isotopic composition were corrected for before applying community-wide circular statistics.

A comparison of consumer $\delta^{13}C$ signatures between different summer sampling seasons revealed that isotopic signature remained similar between most years. The exceptions were summer 2009, where consumer $\delta^{13}C$ signatures were different from all other summers except 2006, and summer 2010, which was significantly different from both summer 2009 and summer 2006 ($p<0.05$) (Table 2.3). When $\delta^{15}N$ values were compared between summers, no significant differences were observed between any years ($p>0.05$).

Consumer assemblage was variable between sampling seasons. Seven consumer species were collected in winter 2010 and at least one summer (Tables 2.1 and 2.2). Out of these seven consumer species, five had $\delta^{13}C$ values were significantly enriched in ^{13}C

in summer compared to winter 2010 : *Anchoa mitichilli* (p=0.004), *Callinectes sapidus* (p=0.04), *Fundulus* sp. (p=0.001), *Mugil cephalus* (p=0.002), and Penaeid shrimp (p=0.007). Two species also had significantly enriched $\delta^{15}N$ values in summer 2009 compared to winter 2010 (*Callinectes sapidus* (p=0.02), *Mugil cephalus* (p=0.04)). No significant differences were observed in either $\delta^{13}C$ or $\delta^{15}N$ values for any consumer species between winter 2010 and summer 2010.

Community-wide shifts in stable isotope expanded upon the cursory information gained from species-specific seasonal and interannual comparisons. We looked first at the shift in stable isotope signatures (both $\delta^{13}C$ and $\delta^{15}N$) between summer 2009 and winter 2010. Consumer organisms became depleted in ^{13}C and slightly enriched in ^{15}N, with a mean vector direction 276.9°(Table 2.4; Figure 2.3a). The component vectors, which represent the movement of individual consumers through isotope space, were highly concentrated, as represented by a mean vector length close to 1.0 (r= 0.9) (Table 2.4). A Rayleigh's test for circular uniformity revealed that this isotopic shift was direction, with component vectors possessing a distribution significantly different from randomness ($p<0.001$)

We next examined the isotopic shift occuring between winter 2010 and the subsequent summer. If the summer 2009 to winter 2010 mean vector were representative of a seasonal pattern, we would expect an opposite complementary shift from winter back to summer. However, the mean vector angle was not in the opposite direction, nor were component vectors significantly directed (μ=313.6°, r=0.60, p=0.26). Individual consumers (represented by component vectors) showed very small changes in isotopic composition, resulting in no net community movement (Figure 2.3b).

To investigate the possibility that the summer 2009- winter 2010 pattern resulted from the unusual nature of summer 2009 (Table 2.3), we compared community isotopic signatures between pooled summer 2002-2008 and winter 2010. The mean vector angle was similar to that observed in the summer 2009- winter 2010 transition (μ= 242.9° and μ= 276.9°, respectively). Constituent vectors were less concentrated (r=0.61), however, the Rayleigh's test indicated that they still exhibited significant directionality (p=0.049). Similar to the summer 2009- winter 2010 transition, consumers became depleted in ^{13}C, but became depleted rather than enriched in ^{15}N (Figure 2.3c).

DISCUSSION

The usefulness of $\delta^{13}C$ values stems from their highly conserved nature, with little fractionation between ultimate carbon sources and top trophic level consumers (Vander Zanden and Rassmussen 2001, Fry 2006). Primary producers within the Nueces Marsh exhibited seasonally stable $\delta^{13}C$ values, while in consumers, in contrast, showed a wide range of $\delta^{13}C$ values depending on collection season. Consumer $\delta^{13}C$ value shifts could not be accounted for by concurrent changes in $\delta^{13}C$ of primary producers, leaving dietary shifts as the most plausible explanation. The enriched $\delta^{13}C$ values of the summer 2009 community likely reflect a substantial reliance on cyanobacterial carbon ($\delta^{13}C = -15.9 \pm 1.0‰$), which peaks in abundance along the Gulf coast during the summer months (MacIntyre et al. 1996). The other primary producers that possess a highly enriched $\delta^{13}C$ signal are C_4 vegetation ($\delta^{13}C = -13.7 \pm 1.0‰$). Two species within the Nueces Marsh possess C_4- type photosynthesis: cordgrass (*Spartina alterniflora*) and saltgrass (*Distichlis spicata*). While both plants show seasonal patterns of production, with biomass peaking in the summer, both *S. alterniflora* and *D. spicata* are present at low densities along the low marsh of the Rincon Bayou channel where consumers were collected (Rasser, Ph.D. dissertation). Secondly, none of the consumers presented in Table 2.1 and 2.2 directly graze on emergent vegetation (DeLancey 1989, Lucas 1982, Laughlin 1982, Odum 1968, Morgan 1980, Zimmerman et al. 2000, Darnell 1961). The pervasive influence of C_3 and C_4 carbon enters the food web by way of the detrital pool (Darnell 1961, Boesch and Turner 1984). It is likely that any increase in C_4 carbon input will be tempered by a concurrent increase in C_3 carbon input, as C_3 emergent plants follow the same seasonal production cycle. Thus, there is no net isotopic enrichment of the detrital pool, making increased cyanobacterial production the most likely source of $\delta^{13}C$ enrichment in summer consumers.

Consumer $\delta^{15}N$ values shifted in a less uniform fashion during the same time period, with a net change in community $\delta^{15}N$ values close to zero. This suggests little movement in trophic position or food chain length during the summer 2009 to winter 2010 transition, despite a shift in diet. Food webs that rely more heavily on detritus tend to have more linkages and longer food chain lengths than those that rely on fresh production (Dekar et al. 2009, Moore et al. 2004). Consumer $\delta^{13}C$ values indicate that

detritus is a major carbon source during both summer and winter, and the lack of notable shift in $\delta^{15}N$ between seasonal components suggests that the importance of detritus remains stable on an annual basis.

The seasonal pattern observed in the summer 2009 – winter 2010 data are supported by comparing mean summer isotopic data from 2000 to 2008 with winter 2010 data. The concentration of the mean vector is lower than the summer 2009 – winter 2010 mean vector (r = 0. 61 and 0.90, respectively), but this is to be expected when integrating interannual variation. Consumers showed a depleted $\delta^{13}C$ values in winter 2010 compared to mean summer values. This again supports a dietary shift between summer and winter, with an increased reliance on an enriched source, such as cyanobacteria, in the summer. However, when comparing mean summer isotopic compositions with winter 2010, there is a trend of depleted $\delta^{15}N$ in the winter.

This depletion in $\delta^{15}N$ winter communities may reflect a shortened food chain during the winter. Akin and Winemiller (2006) examined seasonal food web dynamics Matagorda Bay, TX, and that mean trophic level and number of trophic linkages were lower during the winter. These changes resulted from both an influx of higher trophic level organisms during the summer, as well as shifting consumer diets. Increased microbial activity in the summer might increase the availability of detrital carbon in the summers, lengthening the food web (Buchan et al. 2003). Alternately, the influx of migratory species in the winter might increase resource competition for certain consumers, forcing them to alter their foraging habits and lowering their trophic position. The current study examined only year-round resident species that all represent low trophic level (2- 2.5) organisms. The current data is insufficient to determine the cause of any shift in trophic position, especially as this study marks the first winter sampling effort in this system. Increased winter sampling will help to elucidate what factors impact seasonal shifts in trophic structure.

Despite seeing directed change from summer 2009 – winter 2010 and mean summers – winter 2010, there were no significant shifts in community isotopic values between winter 2010 – summer 2010. If seasonal changes were responsible for the shift in consumer isotope values between summer 2009 – winter 2010, then a mean vector

with an opposite direction and magnitude might be expected from the winter 2010 – summer 2010 transition.

The absence of a corresponding winter-summer isotopic shift makes it difficult to attribute the observed changes between summer and winter to seasonality. However, climate and hydrology in the south Texas coastal bend often follow monsoonal patterns with a high degree of interannual variation in absolute amount and temporal distribution of rainfall (Morton and Donaldson 1978). Environmental factors associated with these climate shifts are likely responsible for both the isotopic transitions observed between summer 2009 – winter 2010 and the lack of change between winter 2010 – summer 2010.

This influence of environmental factors is supported by the isotopic transition between mean summer (2000-2008) – winter 2010. The mean vector has a similar angle (μ=276.9 and 242.9) to that of the summer 2009 – winter 2010 vector, but a shorter length (r= 0.6 and. 0.9, respectively). This suggests that the pattern observed between summer 2009 and winter 2010 is not a spurious trend.

Environmental data from the Nueces Marsh during the sampling period also support the hypothesis that abiotic conditions influence consumer isotopic transitions between seasons. In general, precipitation is higher in the summers and delivered by a small number of intense storm systems (Morton and Donaldson 1978; Tolan 2007). This can lead to a general pattern of summer and winter conditions, but interannual variation is high, and the underlying change is still driven by environmental conditions that are not necessarily correlated with seasonality. This is readily apparent when examining Nueces River flow over the past decade (USGS Water Data for the Nation). Discharge in generally low, with seasonal oscillations of approximately 100 cfs. These regular seasonal fluctuations are dwarfed by periodic flooding events, which increase discharge by upwards of 5000 cfs, but for very short periods of time (Figure 2.4). Similarly, when examining Nueces Marsh salinity, it is apparent that the isotopic transition between summer 2009 – winter 2010 was coincident with a drastic drop in salinity (Figure 2.5). Salinity did not show a corresponding spike during following summer, and likewise isotopic composition remained stable within the consumer community.

The large variation in environmental conditions in south Texas is also apparent when examining drought records across the sampling period. The Nueces watershed

experienced severe drought conditions in summer 2006 and summer 2008, and exceptional drought conditions in summer 2009 (Figure 2.6 c,d,e). In contrast, summers 2002, 2003, and 2010, as well as winter 2010, exhibited very mild drought or normal conditions along the Nueces watershed and coastal bend (Figure 2.6 a,b,f,g).

With a single winter sampling season, it is difficult to ascribe any patterns to seasonality. However, the progression of isotopic shifts in consumers between summer 2009, winter 2010, and summer 2010 suggest that larger patterns of interannual variation may be responsible for shifting consumer diets. These environmental shifts may occur on seasonal boundries, such as the alleviation of drought conditions between summer 2009 and winter 2010. Other times, environmental conditions will remain similar between seasons, such as the precipitation and salinity conditions between winter 2010 and summer 2010.

The shifting isotopic composition of consumers observed between mean summer and winter 2010, and between summer 2009 and winter 2010, suggest that the food web within the Nueces Marsh may respond to changing hydrological regimes. During drought years, low water levels combined with high salinity inhibit emergent vegetation and phytoplankton production (Dunton et al. 2001, Flint 1985). Consumers may then rely more heavily on cyanobacterial carbon sources, assimilating relatively greater portions of this ^{13}C-enriched basal resource. During wetter years, higher freshwater inflow and lower salinities favor phytoplankton and emergent plant production, and cyanobacteral sources may play a lesser role in consumer diets.

The lack of change in consumer $\delta^{15}N$ values is surprising when considering the depleted signature possessed by N-fixing cyanobacteria ($\delta^{15}N$ =0.3‰ ± 0.4). If cyanobacterial consumption is driving consumer enrichment in^{13}C, it would be logical to expect a concurrent depletion in ^{15}N. There are two potential explanations for the lack of response in consumer $\delta^{15}N$ values. First, while consumers may rely more heavily on cyanobacteria during drought conditions, they are certainly still using the emergent vegetation-dominated detrital pool. Emergent vegetation displays a naturally variable $\delta^{15}N$ signature (± 2.0‰), and this inherent disparity may buffer short term changes in diet. Second, enriched $\delta^{13}C$ values were observed during drought conditions, when marsh flushing is lower. This results in increased recycling of the ambient nitrogen pool, which

in turn drives up baseline $\delta^{15}N$ values. Either explanation could account for a cyanobacterial driven shift in consumer $\delta^{13}C$ signatures without a coincident change in $\delta^{15}N$ signatures.

Overall, these data suggest that consumers possess shifting temporal reliance on various sources of organic matter. This is not unusual, with many examples existing in freshwater stream and lake systems (Finley 1999, Walters 2007, Dekar 2009). Seasonal variation in basal resource use has less coverage in estuarine systems, with larger focuses on interannual variation or shifts in individual species (Deegan and Garritt 1997, McMichael and Peters 1987). This data also emphasizes the importance of considering temporal variation when characterizing energy flow and resource utilization within estuarine systems. While there is a long standing paradigm that detrital resources buffer change within salt marsh food webs, local environmental conditions are still important drivers of food web processes (Odum 1968, Haines and Montague 1979, Deegan and Garritt 1997). These local conditions are important to consider when designing management and restoration plans to improve community stability and ecosystem function.

Table 1.1: Summary of hydrographic data collected at each sample site, during each sampling effort. Summer samples were collected during August, and winter samples during March. Data represent surface conditions.

	REF (n=3)	INT (n=1)	WW (n=3)
Summer 2009			
Temperature (°C)	30.4 ± 0.1	30.6	32.4 ± 1.7
Salinity	54.7 ±9.7	48.2	50.8 ± 0.8
DO (mg L^{-1})	5.5 ± 0.1	5.6	5.5 ± 0.7
DO (%)	98.3 ± 7.4	95.9	92.3 ± 11.5
pH	7.5 ± 0.01	7.7	7.7 ± 0.3
Winter 2010			
Temperature (°C)	16.2 ± 0.2	16.1	15.7 ± 1.7
Salinity	16.7 ± 0.02	18.7	18.7 ± 0.5
DO (mg L^{-1})	9.5 ± 0.1	8.3	10.9 ± 1.0
DO (%)	105.9 ± 1.2	93.6	120.9 ± 7.0
pH	7.4 ± 0.1	7.3	7.4 ± 0.2
Summer 2010			
Temperature (°C)	32.7 ± 1.6	31.1	30.9 ± 1.6
Salinity	15.8 ± 1.1	15.4	17.1 ± 0.9
DO (mg L^{-1})	7.0 ± 0.9	6.6	4.9 ± 1.6
DO (%)	105.0 ± 11.5	98.2	72.8 ± 10.7
pH	8.2 ± 0.1	8.3	8.2 ± 0.05

Table 1.2: Mean inorganic-N concentrations for sample sites within the Nueces Marsh. Three replicate samples from summer 2009 were pooled with three replicate samples from summer 2010. No nutrient data available for REF 3.

Site	$NO_3^- + NO_2^{2-}$ (μmol L^{-1})	NH_4^+ (μmol L^{-1})
WW1	188.3 + 7.0	65.2 ± 1.0
WW2	32.5 ± 0.5	58.2 ± 8.0
WW3	20.6 ± 0.8	47.3 ± 6.4
INT	4.0 ± 0.1	5.5 ± 1.8
REF1	6.7 ± 0.1	2.5 ± 1.0
REF2	7.9 ± 0.5	1.1 ± 0.3

Table 1.3: Size range and mean (± standard deviation) $\delta^{15}N$ and $\delta^{13}C$ values for organisms collected at the REF sites in the Nueces Marsh. When n=2, the range in animal size and isotopic signatures are presented. Sizes represent total length for fishes, and shell/carapace width for bivalves and crabs. n= number of individuals sampled. Mean $\delta^{15}N$ and $\delta^{13}C$ values are plotted in Figure 1.4, and organism labels are presented in the right-most column.

Species	n	Size (cm)	$\delta^{15}N$(‰)	$\delta^{13}C$ (‰)	Figure 1.4 label	Trophic guild reference
Producers						
Batis maritima (C_3)	8	--	4.7 ± 2.3	-26.5 ± 1.3	1	
Borrichia frutescens (C_3)	11	--	2.9 ± 1.6	-26.3 ±1.2	1	
Distichlis spicata (C_4)	8	--	5.8 ± 1.4	-13.4 ±1.3	2	
Salicornia virginica (C_3)	10	--	5.4 ± 1.7	-28.4 ±1.1	1	
Spartina alterniflora (C_4)	6	--	4.6 ± 1.5	-13.7 ± 1.0	2	
Sueda maritima (C_3)	5	--	5.8 ± 1.5	-28.6 ± 2.3	1	
POM	4	--	3.4 ± 1.7	-22.3 ± 4.0	3	
Cyanobacteria	6	--	0.3 ± 0.4	-15.1 ± 0.5	4	
Planktivores						
Anchoa mitchilli (Bay anchovy)	15	3.8-4.8	13.6 ± 1.3	-20.4 ± 1.6	5	DeLancey 1989
Brevoortia patronus (Gulf menhaden)	8	3.7-7.1	12.7 ± 1.6	-20.2 ±1.8	6	Castillo-Rivera et al. 1996
Dorosoma cepedianum (Gizzard shad)	4	4.8-27.6	11.7 ± 0.6	-19.6 ± 0.6	7	Miller 1960
Menidia peninsulae (Tidewater silverside)	12	4.6-6.9	12.1 ± 0.9	-18.0 ± 1.4	8	Lucas 1982
Rangia clam	5	0.7-1.3	7.8 ± 1.5	-13.3 ± 4.0	9	Sullivan and Moncreiff 1990
Zooplankton	1	--	7.3	-23.3	10	
Detritivores						
Callinectes sapidus (Blue crab)	12	1.1-10.2	9.6 ± 3.5	-20.9 ± 1.7	11	Laughlin 1982

Cyprinodon variegatus (Sheepshead minnow)	4	2.0-2.4	8.4 ± 0.8	-15.9 ± 1.5	12	D'Avanzo and Valiela 1990
Mugil cephalus (Striped mullet)	8	3.0-18.7	7.0 ± 1.2	-17.8 ± 4.1	13	Odum 1968
Palaemonetes shrimp	7	2.0-2.9	10.5 ± 1.6	-17.8 ± 1.4	14	Morgan 1980
Penaeid shrimp	14	3.0-8.3	9.9 ± 2.3	-19.2 ± 1.7	15	Zimmerman et al. 2000
Zoobenthic carnivores						
Citharichthys spilopterus (Bay whiff)	3	3.5-6.4	11.1 ± 1.7	-18.5 ± 0.5	16	Toepfer and Fleeger 1995
Fundulus grandis (Gulf killifish)	4	2.6-5.1	9.5 ± 0.3	-19.7 ± 2.4	17	Lipcius and Subrahmanyam 1986
Fundulus similis (Long-nose killifish)	6	4.4-5.0	9.6 ±0.8	-17.8 ± 1.0	18	Lipcius and Subrahmanyam 1986
Gobioides broussonnetii (Violet goby)	2	2.1-3.7	10.0-13.0	-23.2 to -21.2	19	Mata-Cortes et al. 2004
Gobisoma bosc (Naked goby)	5	5.0-13.0	10.9 ± 0.8	-20.4 ± 1.2	20	Hendon et al. 2000
Lagodon rhomboides (Pinfish)	6	5.9-6.3	11.3 ± 1.9	-19.8 ± 2.1	21	Potthoff and Allen 2003
Leiostomus xanthurus (Spot croaker)	3	5.8-6.4	11.7 ± 1.9	-19.4 ± 0.9	22	Ellis and Coull 1989
Micropogonias undulatus (Atlantic croaker)	6	11.5-17.5	12.8 ± 0.9	-19.6 ± 1.1	23	Overstreet and Heard 1978
Piscivores						
Ariopsis felis (Hardhead catfish)	6	19.5-24.5	14.4 ± 0.3	-18.9 ± 0.7	24	Motta et al. 1995
Cynoscion nebulosus (Spotted seatrout)	4	4.5-10.2	12.1 ± 1.1	-19.4 ± 2.3	25	McMichael and Peters 1989
Sciaenops ocellatus (Red drum)	5	3.4-5.1	11.5 ± 1.1	-18.3 ± 1.0	26	Peters and McMichael 1987

Table 1.3, continued

Table 1.4: Size range, mean (± standard deviation) $\delta^{15}N$, and $\delta^{13}C$ values for organisms collected at the WW site in the Nueces Marsh. When n=2, the range in animal size and isotopic signatures are presented. Sizes represent total length for fishes, and shell/carapace width for bivalves and crabs. n= number of individuals sampled. Mean $\delta^{15}N$ and $\delta^{13}C$ values are plotted in Figure 1.3, and organism labels are presented in the right-most column.

Species	n	Size (cm)	$\delta^{15}N$(‰)	$\delta^{13}C$ (‰)	Figure 1.3 label	Trophic guild reference
Producers						
Batis maritima (C_3)	10	--	8.4 ± 2.2	-26.6 ± 1.6	1	
Borrichia frutescens (C_3)	10	--	5.9 ± 1.0	-26.9 ±2.4	1	
Distichlis spicata (C_4)	4	--	9.1 ± 1.1	-14.7 ± 0.6	2	
Salicornia virginica (C_3)	10	--	10.2 ± 2.5	-28.2 ± 2.5	1	
Spartina alterniflora (C_4)	8	--	9.8 ± 0.9	-13.5 ± 1.2	2	
Sueda maritima (C_3)	4	--	10.8 ± 4.4	-26.7 ± 1.4	1	
POM	4	--	5.7 ± 2.5	-22.6 ± 3.6	3	
Cyanobacteria	6	--	1.6 ± 0.1	-15.9 ± 0.6	4	
Planktivores						
Anchoa mitchilli (Bay anchovy)	19	3.0-5.1	14.4 ± 2.4	-20.2 ± 1.4	5	DeLancey 1989
Brevoortia patronus (Gulf menhaden)	6	3.3-7.0	13.9 ± 0.7	-21.2 ±1.6	6	Castillo-Rivera et al. 1996
Dorosoma cepedianum (Gizzard shad)	2	4.0-4.2	12.4-14.4	-20.4 to -19.8	7	Miller 1960
Menidia peninsulae (Tidewater silverside)	6	4.6-6.9	13.4 ± 1.5	-19.1 ± 1.7	8	Lucas 1982
Rangia clam	3	0.6-0.9	9.1 ± 2.5	-16.5 ± 3.1	9	Sullivan and Moncreiff 1990
Zooplankton	1	--	9.5	-22.4	10	
Detritivores						
Callinectes sapidus (Blue crab)	8	1.8-12.0	12.2 ± 1.9	-19.7 ± 2.1	11	Laughlin 1982
Cyprinodon variegatus (Sheepshead minnow)	13	2.5-3.6	11.3 ± 1.9	-16.4 ± 2.3	12	D'Avanzo and Valiela 1990

Mugil cephalus (Striped mullet)	18	3.0-28.5	11.2 ± 2.4	-16.6 ± 3.4	13	Odum 1968
Palaemonetes shrimp	4	1.9-2.1	14.3 ± 0.9	-18.1 ± 0.8	14	Morgan 1980
Penaeid shrimp	12	5.6-9.0	12.6 ± 1.8	-18.4 ± 1.7	15	Zimmerman et al. 2000
Zoobenthic carnivores						
Citharichthys spilopterus (Bay whiff)	2	2.0-2.5	14.8-14.9	-18.4 to -17.8	16	Toepfer and Fleeger 1995
Fundulus grandis (Gulf killifish)	8	2.2-5.9	13.1 ± 3.1	-17.6 ± 1.0	17	Lipcius and Subrahmanyam 1986
Fundulus similis (Long-nose killifish)	9	3.1-5.1	14.2 ± 1.2	-16.9 ± 1.6	18	Lipcius and Subrahmanyam 1986
Gobioides broussonnetii (Violet goby)	4	7.3-8.7	11.6 ± 1.2	-19.2 ± 1.6	19	Mata-Cortes et al. 2004
Gobisoma bosc (Naked goby)	3	2.1-5.5	14.9 ± 1.1	-20.1 ± 2.7	20	Hendon et al. 2000
Lagodon rhomboides (Pinfish)	4	6.2-9.0	14.7 ± 1.2	-19.3 ± 1.9	21	Potthoff and Allen 2003
Leiostomus xanthurus (Spot croaker)	7	3.8-12.9	14.5 ± 2.0	-18.8 ± 1.7	22	Ellis and Coull 1989
Micropogonias undulatus (Atlantic croaker)	5	9.0-9.6	14.6 ± 1.2	-19.3 ± 1.7	23	Overstreet and Heard 1978
Piscivores						
Ariopsis felis (Hardhead catfish)	6	7.4-37.0	15.2 ± 1.0	-19.4 ± 1.4	24	Motta et al. 1995
Cynoscion nebulosus (Spotted seatrout)	4	5.3-10.9	13.6 ± 0.6	-21.3 ± 1.4	25	McMichael and Peters 1989
Scianops ocellatus (Red drum)	4	3.0-3.8	17.3 ± 2.2	-16.7 ± 0.9	26	Peters and McMichael 1987

Table 1.4, continued

Table 1.5: Trophic levels of organisms collected from the Nueces Marsh, TX. Trophic calculations are based on a fractionation factor of 3.8‰ for POM-based trophic pathways and 3.5‰ for detrital based pathways.

Trophic level	Organisms
1. Primary producers	POM, emergent vegetation, cyanobacteria
2. Primary consumers	
Planktivores	Zooplankton : 2.0
	Rangia clams : 2.1
	Menidia peninsulae : 2.3
Benthic grazers	*Mugil cephalus* : 2.0
	Palaemonetes sp. : 2.0
Detritivores	*Cyprinodon variegatus* : 2.4
	Callinectes sapidus : 2.7
	Fundulus grandis : 2.7
	Fundulus similis : 2.7
	Penaeid shrimp : 2.8
	Gobioides broussonettii : 2.8
3. Secondary consumers	
Omnivores	*Citharichthys spilopterus* : 3.1
	Gobisoma bosc : 3.1
Zooplanktivores	*Brevoortia patronus* : 3.4
	Anchoa mitchilli : 3.6
Zoobenthic predators	*Lagodon rhomboides* : 3.2
	Leiostomus xanthurus : 3.3
	Micropogonius undulatus : 3.6
Minor piscivores	*Scianops ocellatus* : 3.2
	Cynoscion nebulosus : 3.4
4. Tertiary consumers	
Benthic carnivore	*Ariopsis felis* : 4.1

Table 2.1: Mean (± standard deviation) $\delta^{13}C$ values for producer and consumer species collected between 2002 and 2010 (n.d. indicates no data). Sample size = 3-8 individuals.

Species	Summer 2002	Summer 2003	Summer 2006	Summer 2008	Summer 2009	Winter 2010	Summer 2010
Batis maritima	n.d.	-27.77 (± 0.2)	n.d.	n.d.	-26.68 (± 1.4)	-27.57 (± 0.8)	-27.06 (± 0.4)
Borrichia frutescens	n.d.	n.d.	-30.07 (± 2.7)	n.d.	-25.28 (± 0.4)	-27.06 (± 0.8)	-26.79 (± 1.6)
Spartina alterniflora	n.d.	n.d.	n.d.	-14.70 (± 0.5)	-13.85 (± 0.4)	-14.80 (± 0.1)	-12.54 (± 0.2)
POM	n.d	-23.57 (0.2)	n.d.	-19.72 (± 0.9)	-23.54 (± 0.4)	-22.85 (± 0.5)	-23.44 (± 0.3)
Cyanobacteria	n.d.	-15.14 (±0.5)	n.d.	n.d.	-14.94 (± 0.5)	n.d.	-15.24 (± 0.3)
Achirus lineatus (Lined sole)	n.d.	-19.91	n.d.	n.d.	-18.27 (± 0.1)	n.d	-21.13 (± 0.6)
Anchoa mitchilli (Bay anchovy)	-21.68 (± 0.6)	-22.00 (± 0.1)	-20.57 (± 0.1)	-20.91 (± 0.9)	-19.11 (± 1.1)	-21.25 (± 0.9)	-21.36 (± 0.4)
Ariopsis felis (Hardhead catfish)	n.d.	-18.77 (± 0.2)	n.d.	-20.44 (± 1.0)	-18.87 (± 0.7)	n.d.	n.d.
Bagre marinus (Gafftop catfish)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-20.83
Bothus sp. (Left eyed flounder)	-19.10 (±0.5)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Brevoortia patronus (Gulf menhaden)	-20.39 (± 0.7)	-22.04 (± 0.7)	-20.21 (± 0.5)	-20.45	-18.89 (± 1.4)	n.d.	-21.44 (± 1.1)

Callinectes sapidus (Blue crab)	-24.14 (± 0.9)	-21.12 (± 0.4)	-21.82 (± 0.3)	-18.07 (± 0.3)	-18.19 (± 1.2)	-21.28 (± 1.4)	-21.63 (± 1.1)
Citharichthys spilopterus (Bay Whiff)	n.d.	-20.00 (± 0.1)	n.d.	n.d.	-18.52	-19.04	-17.99
Cynoscion arenarius (Sand trout)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-20.87
Cynoscion nebulosus (Spotted seatrout)	n.d.	-19.75 (±0.3)	n.d.	-17.88 (± 0.4)	-17.56 (± 1.7)	n.d.	-21.18 (± 0.1)
Cyprinodon variegatus (Sheepshead minnow)	-17.35 (± 0.4)	n.d.	n.d.	n.d.	n.d.	-15.88 (± 1.5)	n.d.
Dorosoma cepedianum (Gizzard shad)	n.d.	n.d.	n.d.	n.d.	-19.64 (± 0.6)	n.d.	n.d.
Elops saurus (Ladyfish)	n.d.	n.d.	n.d.	-19.22	n.d.	n.d.	n.d.
Eucinostomus argentus (Spotfin mojarra)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-20.23
Penaeid shrimp	-14.66 (± 0.1)	-19.03 (± 0.6)	-16.53 (± 1.4)	-18.76 (± 0.8)	-17.94 (± 0.7)	-20.59 (±1.1)	-20.90 (± 1.2)
Fundulus sp. (Killifish)	-16.97 (± 0.3)	n.d.	-17.14 (± 0.4)	n.d.	-17.33 (± 0.7)	-20.19 (± 1.8)	n.d.
Gobioides broussonnetii (Violet goby)	n.d.	-16.67	n.d.	n.d.	n.d.	-21.24	-23.23

Table 2.1, continued

Gobisoma bosc (Naked goby)	n.d.	-18.90 (0.3)	n.d.	n.d.	-19.83 (± 0.8)	n.d.	-21.22 (± 1.3)
Harengula pensicola (Scaled sardine)	n.d.	n.d.	n.d.	n.d.	n.d.	-22.71 (± 0.4)	n.d.
Laconereis culveri (Nereid polychaete)	n.d.	-19.14 (±0.4)	-15.19 (± 1.8)	n.d.	n.d.	n.d.	n.d.
Lagodon rhomboides (Pinfish)	-19.11 (± 0.5)	n.d.	n.d.	-19.82 (±0.4)	-18.18 (± 0.6)	n.d.	-21.42 (±1.5)
Leiostomus xanthurus (Spot croaker)	n.d.	-19.38 (±0.9)	n.d.	n.d.	n.d.	n.d.	-19.45 (± 0.8)
Lolliguncula brevis (Breif squid)	-22.70	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Marphysa sanguinea (Polychaete)	n.d.	n.d.	-16.64 (± 0.2)	n.d.	n.d.	n.d.	n.d.
Menidia peninsulae (Tidewater silverside)	-19.25 (± 0.8)	-21.24 (± 0.3)	n.d.	n.d.	-16.64 (± 1.2)	-18.12 (± 0.8)	-18.85 (± 1.5)
Micropogonius undulatus (Atlantic croaker)	n.d.	n.d.	n.d.	-19.89 (± 0.2)	-19.00 (± 0.8)	n.d.	-20.78 (± 0.5)
Mugil cephalus (Striped mullet)	-15.96 (± 1.9)	-14.44 (± 0.7)	n.d.	-17.54 (± 0.3)	-14.33 (± 0.1)	-20.75 (± 1.3)	n.d.

Table 2.1, continued

Oligoplites saurus (Leatherjack)	n.d.	n.d.	n.d.	n.d.	-13.91	n.d.	n.d.
Opsanus beta (Toadfish)	-23.41	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Palaemonetes sp. (Grass shrimp)	n.d.	-19.19 (± 0.1)	n.d.	-19.45 (± 0.3)	-16.81 (± 0.6)	-18.52 (± 1.4)	n.d.
Paralichthys lethostigma (Southern flounder)	n.d	n.d.	n.d.	n.d.	-17.65	n.d.	n.d.
Peprilus paru (Harvestfish)	n.d.	n.d.	n.d.	n.d.	-19.62 (± 0.5)	n.d.	n.d.
Pogonias cromis (Black drum)	n.d.	n.d.	n.d.	n.d.	-15.41	n.d.	n.d.
Rangia sp. (Clam)	n.d	n.d.	n.d.	-24.24 (± 0.3)	n.d.	n.d.	n.d.
Scianops ocellatus (Red drum)	n.d.	n.d.	n.d.	n.d.	n.d.	-18.30 (± 1.0)	n.d.
Strongulura marina (Atlantic needlefish)	-19.47 (± 1.1)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 2.1, continued

Table 2.2: Mean (± standard deviation) $\delta^{15}N$ values for producer and consumer species collected between 2002 and 2010 (n.d. indicates no data). Sample size = 3-8 individuals.

Species	Summer 2002	Summer 2003	Summer 2006	Summer 2008	Summer 2009	Winter 2010	Summer 2010
Batis maritima	n.d.	5.83 (±0.7)	n.d.	n.d.	2.79 (± 1.2)	5.99 (± 0.1)	7.19 (± 0.4)
Borrichia frutescens	n.d	n.d.	3.56 (±1.2)	n.d.	1.46 (± 0.5)	3.58 (± 2.0)	3.72 (± 0.3)
Spartina alterniflora	n.d.	n.d.	n.d.	5.55 (± 0.6)	5.21 (± 0.2)	2.77 (± 0.7)	5.69 (± 1.2)
POM	n.d.	n.d	n.d.	4.8 (±1.5)	5.7 (± 1.7)	3.6 (±1.3)	3.4 (± 0.8)
Cyanobacteria	n.d.	0.49	n.d.	n.d.	0.3 (± 0.4)	n.d.	0.6 (±0.3)
Achirus lineatus (Lined sole)	n.d.	10.82	n.d.	n.d.	10.88 (± 0.2)	n.d.	10.27 (± 1.4)
Anchoa mitchilli (Bay anchovy)	13.23 (± 0.1)	12.27 (± 0.2)	13.76 (±0.4)	12.80 (± 0.9)	14.24 (± 1.4)	13.76 (± 1.7)	12.36 (± 0.4)
Ariopsis felis (Hardhead catfish)	n.d.	14.31 (± 0.9)	n.d.	13.88 (± 0.9)	14.36 (± 0.3)	n.d.	n.d.
Bagre marinus (Gafftop catfish)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	14.27
Bothus sp. Left eyed flounder	12.23 (± 0.3)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Brevoortia patronus (Gulf menhaden)	8.25	12.00 (± 2.9)	12.80 (± 0.6)	11.91	11.76 (± 1.7)	n.d.	13.71 (± 0.3)
Callinectes sapidus (Blue crab)	5.98 (± 0.3)	10.34 (± 0.1)	11.43 (± 0.1)	9.90 (± 0.4)	14.66 (± 4.0)	7.17 (±1.6)	9.4 (± 2.7)
Citharichthys spilopterus (Bay whiff)	n.d.	14.62 (± 0.4)	n.d.	n.d.	12.28	11.84	9.18
Cynoscion arenarius (Sand trout)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	14.52
Cynoscion nebulosus (Spotted seatrout)	n.d.	13.04 (± 0.2)	n.d.	13.06 (± 0.5)	12.57 (± 1.3)	n.d.	11.63 (± 0.9)
Cyprinodon variegatus (Sheepshead minnow)	6.36 (± 0.6)	n.d.	n.d.	n.d.	n.d.	8.35 (± 0.8)	n.d.
Dorosoma cepedianum (Gizzard shad)	n.d.	n.d.	n.d.	n.d.	11.70 (± 0.6)	n.d.	n.d.

Eucinostomus argentus (Spotfin mojarra)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	9.25
Elops saurus (Ladyfish)	n.d.	n.d.	n.d.	10.50	n.d.	n.d.	n.d.
Penaeid shrimp	6.07 (± 0.9)	9.76 (± 0.3)	9.19 (± 1.8)	9.49 (± 0.4)	10.00 (± 2.3)	9.27 (± 2.3)	10.20 (± 2.3)
Fundulus sp. (Killifish)	10.92 (± 0.3)	n.d.	9.19 (± 0.9)	n.d.	9.31 (± 0.5)	9.98 (± 0.7)	n.d.
Gobioides broussonnetii (Violet goby)	n.d.	8.92	n.d.	n.d.	n.d.	13.07	9.99
Gobisoma bosc (Naked goby)	n.d.	10.79 (± 0.1)	n.d.	n.d.	11.11 (± 0.8)	n.d.	7.78 (± 3.3)
Harengula pensacolae (Scaled sardine)	n.d.	n.d.	n.d.	n.d.	n.d.	13.64	n.d.
Laconereis culveri (Nereid polychaete)	n.d.	6.10 (± 0.1)	8.17 (± 1.0)	n.d.	n.d.	n.d.	n.d.
Lagodon rhomboides (Pinfish)	11.85 (± 0.1)	n.d.	n.d.	11.10 (± 0.5)	11.42 (± 0.9)	n.d.	9.46 (± 0.3)
Leiostomus xanthurus (Spot croaker)	n.d.	13.63 (± 3.0)	n.d.	n.d.	n.d.	n.d.	11.68 (± 1.0)
Lolliguncula brevis (Breif squid)	14.31	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Marphysa sanguinea (Polychate worm)	n.d.	n.d.	8.00 (± 0.3)	n.d.	n.d.	n.d.	n.d.
Menidia peninsulae (Tidewater silverside)	13.61 (±0.2)	12.45 (± 0.2)	n.d.	n.d.	11.66 (± 0.4)	12.08 (± 0.6)	12.58 (± 1.3)
Micropogonias undulatus (Atlantic croaker)	n.d.	n.d.	n.d.	13.96 (± 1.6)	13.21 (± 0.9)	n.d.	12.07 (± 0.1)
Mugil cephalus (Striped mullet)	11.47 (± 4.0)	9.49 (± 1.4)	n.d.	9.84 (± 0.8)	8.19 (± 0.5)	6.28 (± 1.1)	n.d.
Oligoplites saurus (Leatherjack)	n.d.	n.d.	n.d.	n.d.	13.02	n.d.	n.d.
Opsanus beta (Toadfish)	8.69	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Palaemonetes sp. (Grass shrimp)	n.d.	10.19 (± 0.2)	n.d.	10.96 (± 1.3)	10.47 (± 1.0)	10.57 (± 1.9)	n.d.

Table 2.2, continued

Paralichthys lethostigma (Southern flounder)	n.d.	n.d.	n.d.	n.d.	14.02	n.d.	n.d.
Peprilus paru (Harvestfish)	n.d.	n.d.	n.d.	n.d.	15.56 (± 0.68)	n.d.	n.d.
Pogonius cromis (Black drum)	n.d.	n.d.	n.d.	n.d.	10.69	n.d.	n.d.
Rangia sp. (Clam)	n.d.	n.d.	n.d.	7.79 (± 0.1)	7.80 (± 1.5)	n.d.	n.d.
Scianops ocellatus (Red drum)	n.d.	n.d.	n.d.	n.d.	n.d.	11.51 (± 1.1)	n.d.
Strongylura marina (Atlantic needlefish)	15.13 (± 3.5)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 2.2, continued

Table 2.3: P-values from a pairwise ANOVA of consumer $\delta^{13}C$ values between summers. Significant p-values are bolded. Summers are similar with the exception of summer 2009, which is significantly different from all summers except 2006, and summer 2010, which is significantly different from both summer 2009 and 2006.

	Summer 2002	Summer 2003	Summer 2006	Summer 2008	Summer 2009
Summer 2003	0.87	-	-	-	-
Summer 2006	0.19	0.22	-	-	-
Summer 2008	0.81	0.66	0.12	-	-
Summer 2009	**0.02**	**0.02**	0.53	**0.01**	-
Summer 2010	0.10	0.05	**0.01**	0.15	**1.1e-05**

Table 2.4: Mean vector angle (μ), length (r), and standard error (SE) of food web temporal gradients in the Nueces Marsh.

	Mean vector			Rayleigh's Test	
Gradient	μ	r	SE	Z	p
Summer 2009-Winter 2010	276.9°	0.90	12.9	5.6	<0.001
Winter 2010-Summer 2010	313.6°	0.60	58.4	1.4	0.26
Mean Summer-Winter 2010	242.9°	0.61	56.2	2.7	0.05

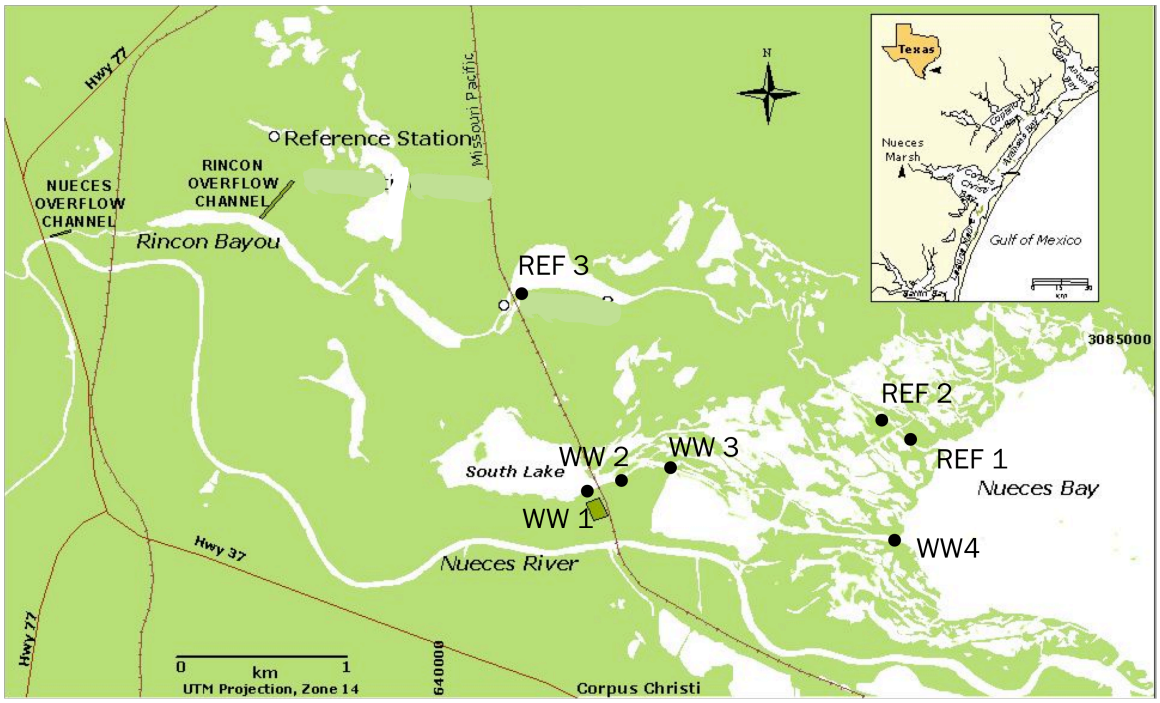

Figure 1.1: Map depicting sampling stations within the Nueces Marsh. Water chemistry and inorganic nutrient samples were collected and analyzed independently for each station. Isotope samples were collected and pooled into three sites: WW (stations WW1, WW2, and WW3), INT (station WW4), and REF (stations REF1, REF2, and REF3).

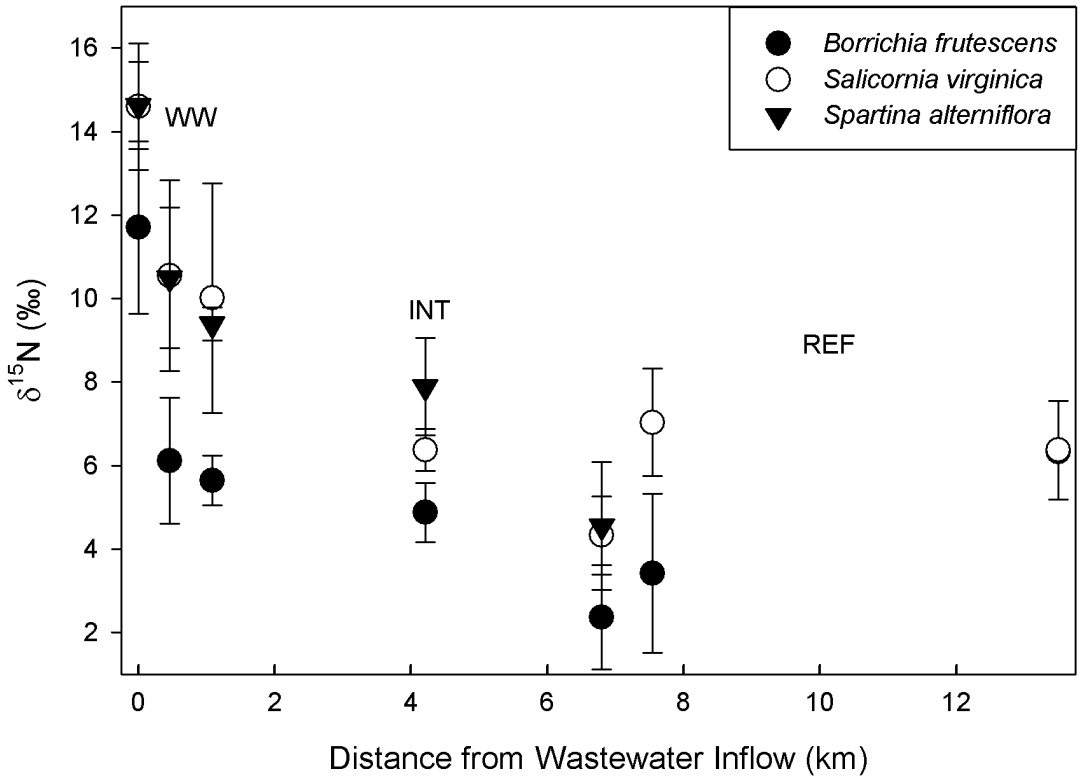

Figure 1.2: The $\delta^{15}N$ values of three species of emergent vegetation along the WW and REF channels. The plants display decreasing $\delta^{15}N$ signatures with increasing distance from where treated wastewater enters the marsh.

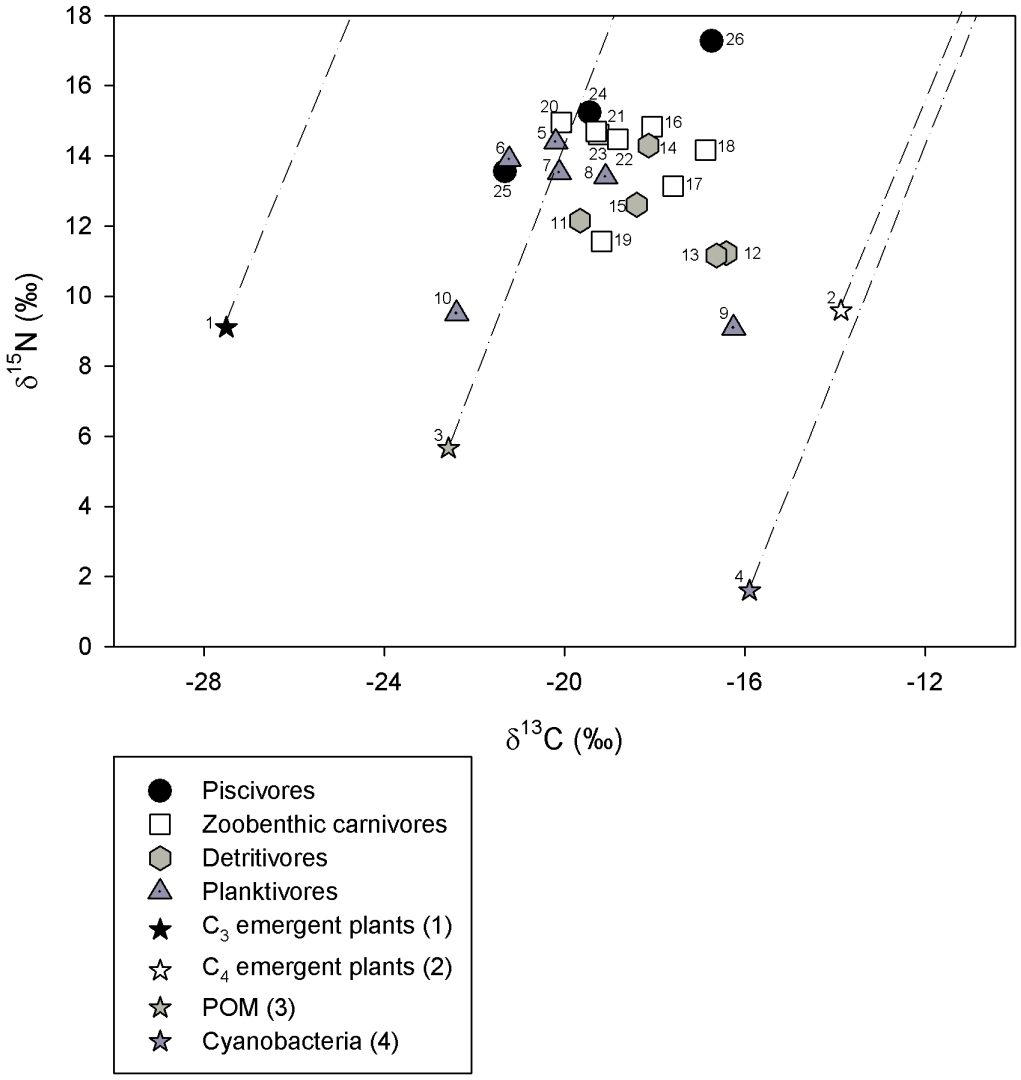

Figure 1.3: $\delta^{13}C$: $\delta^{15}N$ biplot of producers and consumers collected at the WW site. Primary producers are grouped into four catagories: C_3 plants, C_4 plants, cyanobacteria, and particulate organic matter (POM). Dashed lines indicate projected $^{15}N/^{13}C$ trophic enrichments expected for consumers relying on each primary producer. Consumer symbols represent mean isotopic signatures, and consumers were sorted into four trophic guilds based on literature diet references. Species names, standard error, and sample sizes are presented in Table 1.4. Consumer $\delta^{13}C$ values cluster around the POM enrichment line, however, elevated $\delta^{15}N$ signatures reflect the integration of other carbon sources.

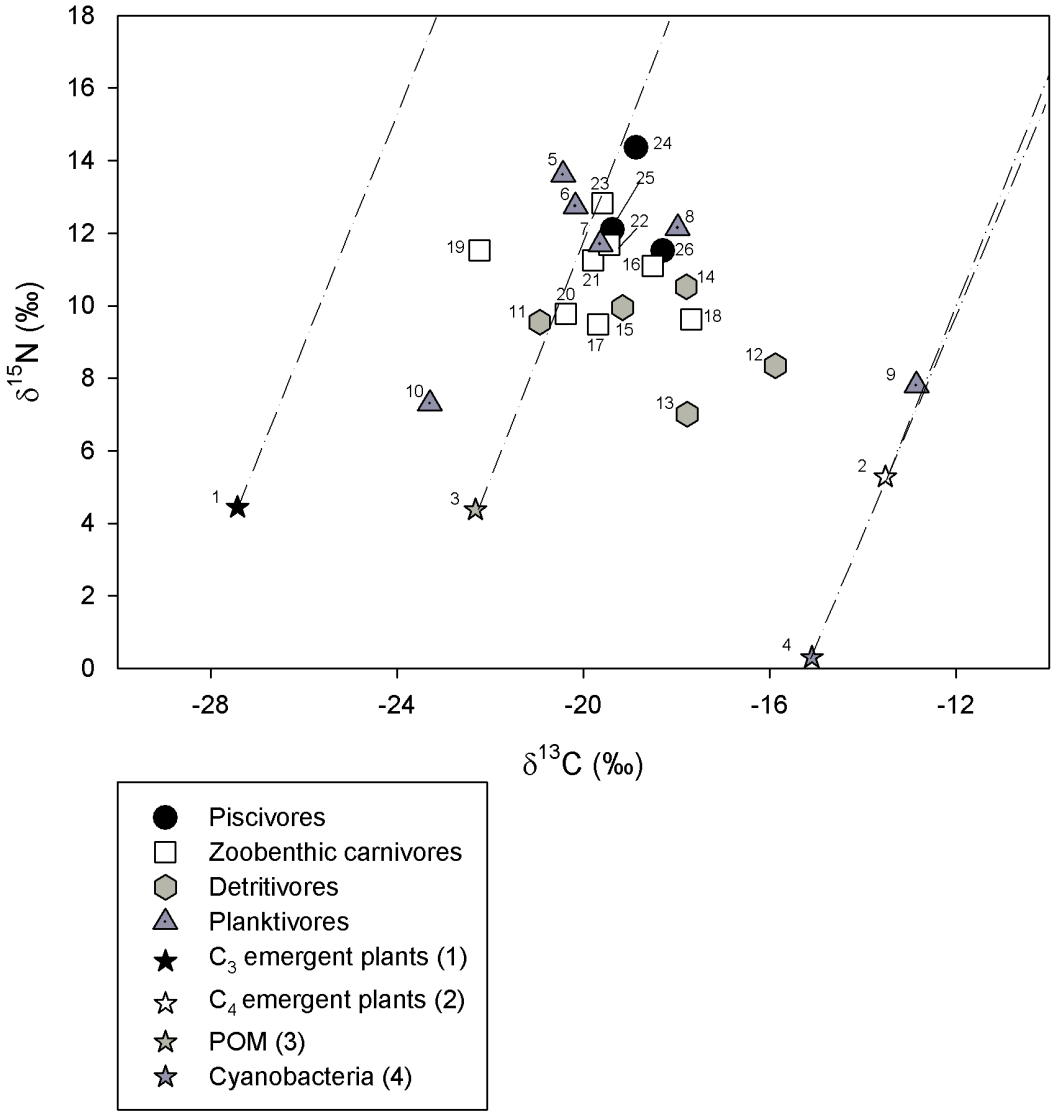

Figure 1.4: $\delta^{13}C$: $\delta^{15}N$ biplot of producers and consumers collected at the REF site. Primary producers are grouped into four catagories: C_3 plants, C_4 plants, cyanobacteria, and particulate organic matter (POM). Dashed lines indicate projected $^{15}N/^{13}C$ trophic enrichments expected for consumers relying on each primary producer. Consumer symbols represent mean isotopic signatures, and consumers were sorted into four trophic guilds based on literature diet references. Species names, standard error, and sample sizes are presented in Table 1.3. Consumer isotope values appear to cluster around the POM enrichment line.

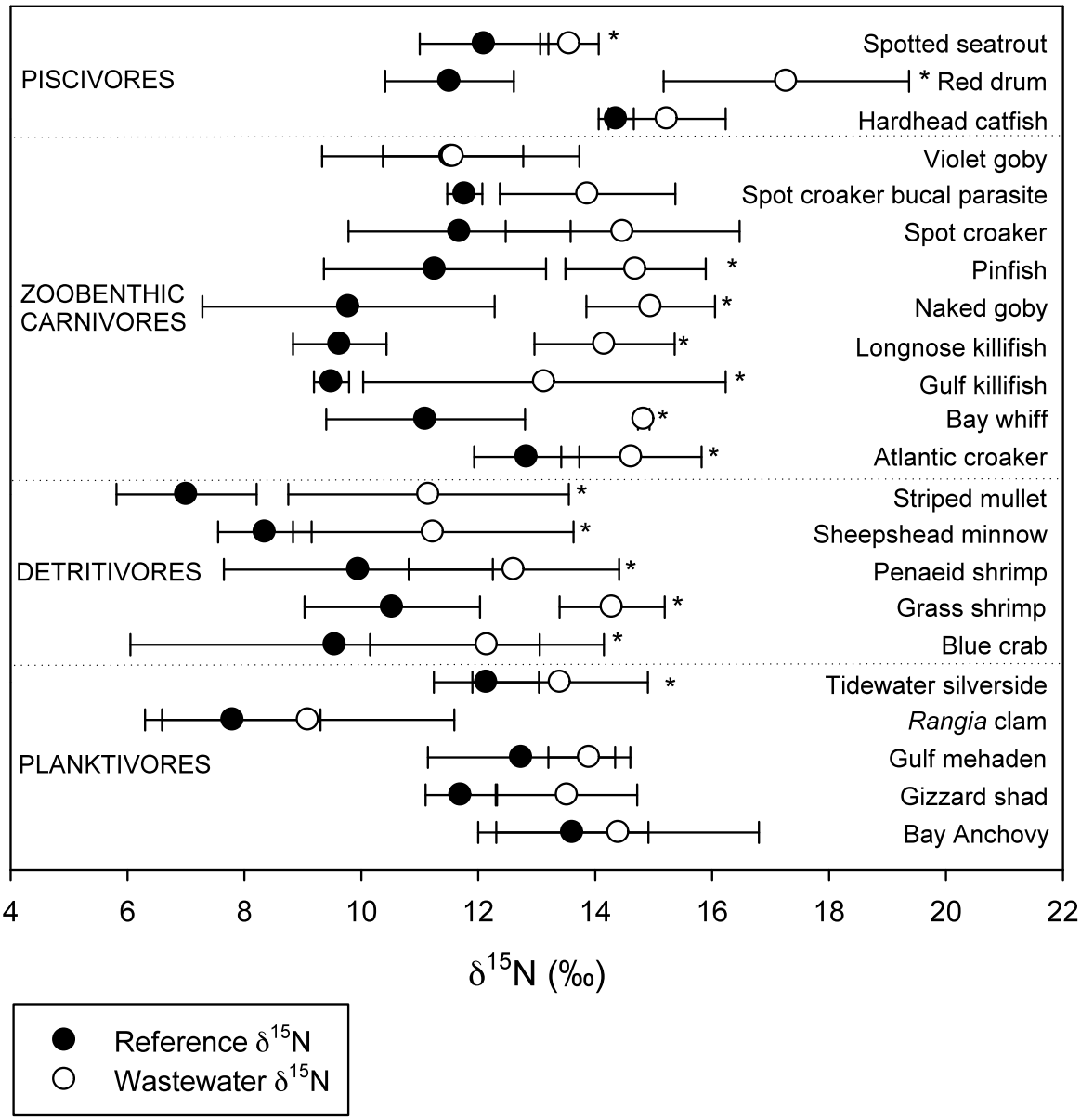

Figure 1.5: Mean $\delta^{15}N$ (± SD) of consumer species collected at reference (filled circles) and wastewater (open circles) sites. Consumers from WW with $\delta^{15}N$ values significantly different ($p<0.05$) from their REF counterparts are indicated with an asterisk (*).Consumers are grouped according to literature-based trophic guilds. Overall, biota from the WW site are ^{15}N enriched to the REF site, with the exception of most planktivorous species.

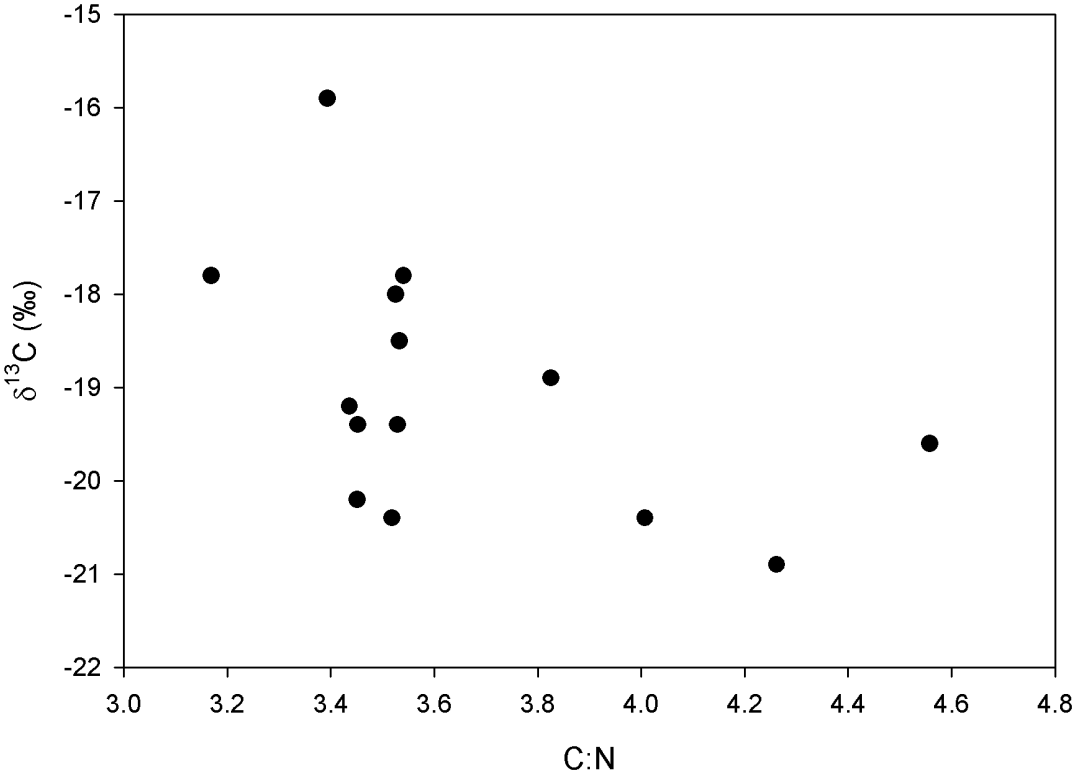

Figure 1.6: Consumer $\delta^{13}C$ values plotted against tissue C:N ratio. Previous studies have found negative relationships between C:N ratio and $\delta^{13}C$ signatures, related to significant ^{13}C-depleted lipid contributions. No relationship was observed between C:N ratios and $\delta^{13}C$ values in Nueces Marsh consumers ($R^2 = 0.15$, $p=0.07$).

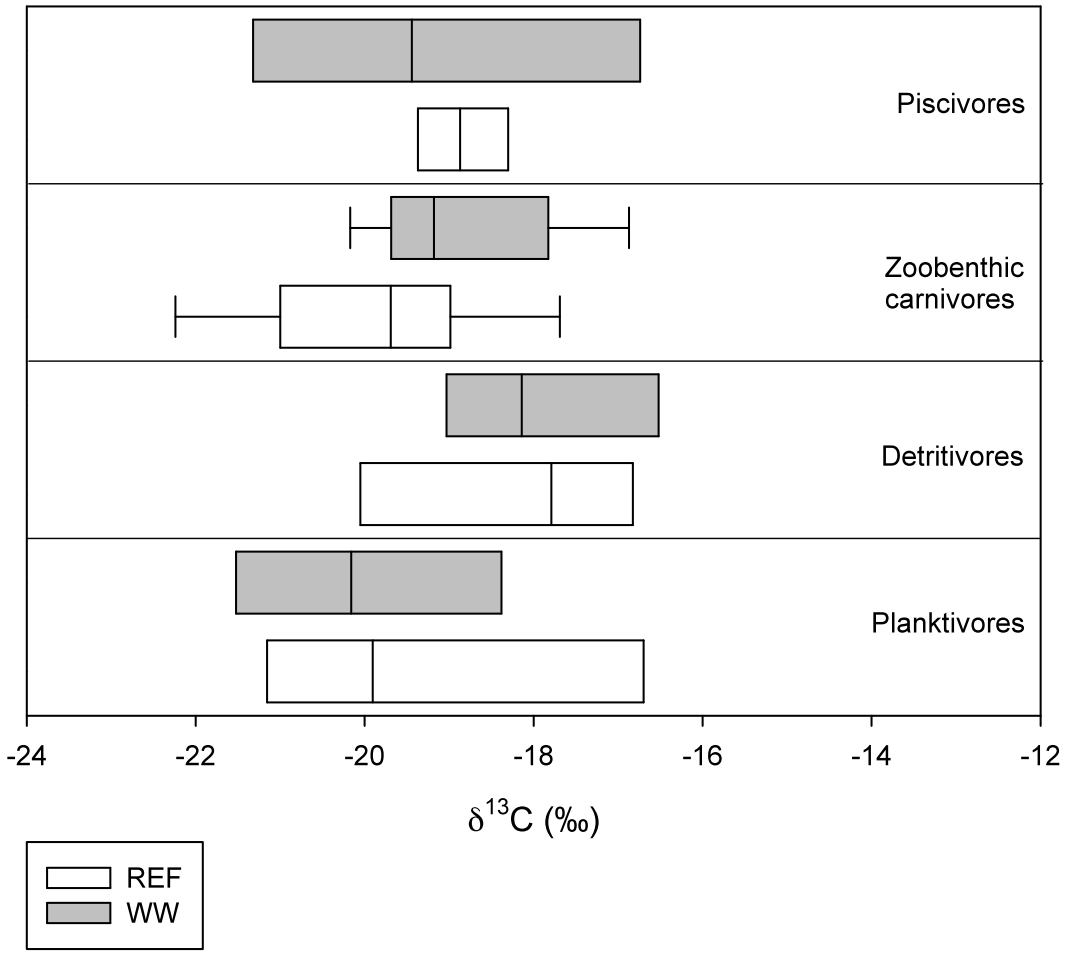

Figure 1.7: Boxplot depicting $\delta^{13}C$ isotope space occupied by trophic guilds from REF and WW. Center lines represent the median, with outside edges of the box representing the 1st and 3rd quartiles. Whiskers represent outliers.

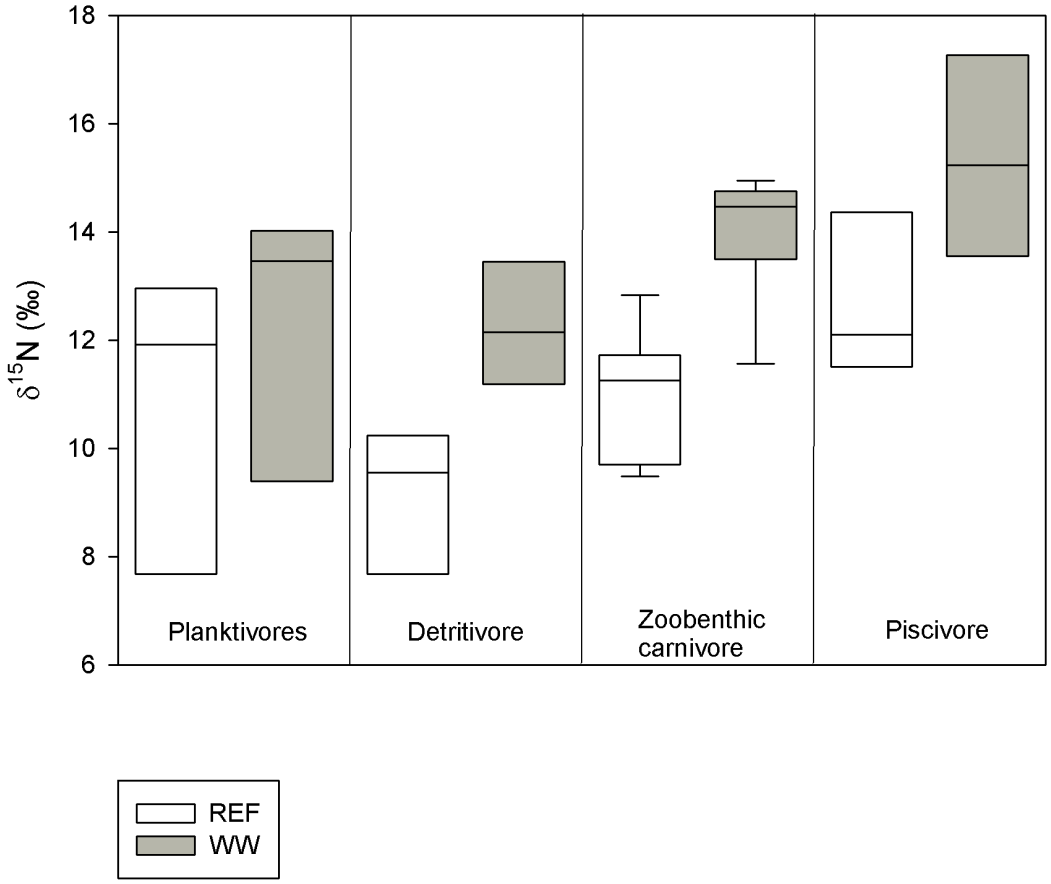

Figure 1.8: Boxplot depicting $\delta^{15}N$ isotope space occupied by trophic guilds from REF and WW. Center lines represent the median, with outside edges of the box representing the 1st and 3rd quartiles. Whiskers represent outliers.

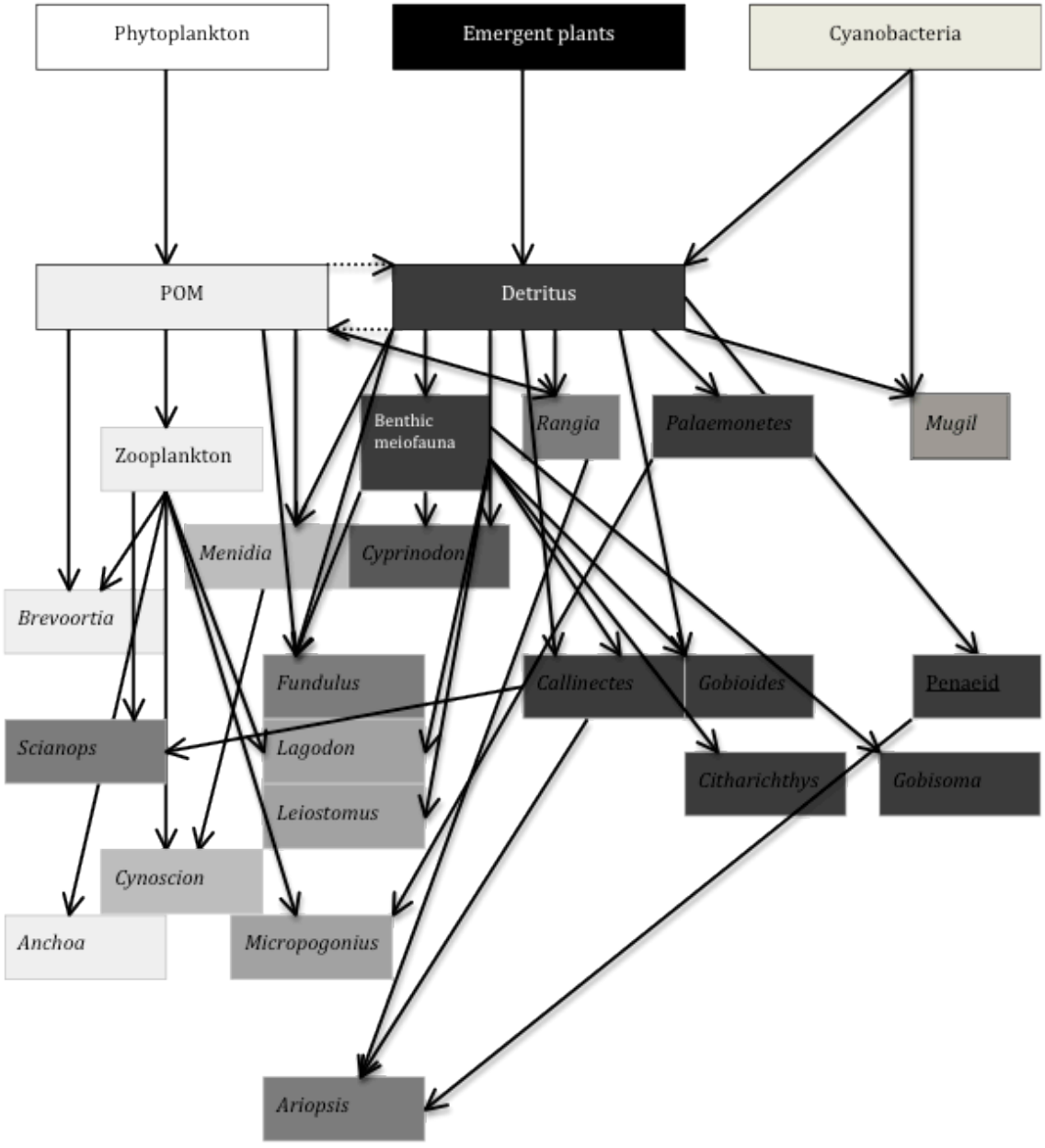

Figure 1.9: Simplified diagram representing the trophic structure of the Nueces Marsh. Shading represents the importance of various carbon source end members to particular consumers. The prevalence of dark shading, even in higher trophic levels, is indicative of the pervasive influence of detritus in this food web.

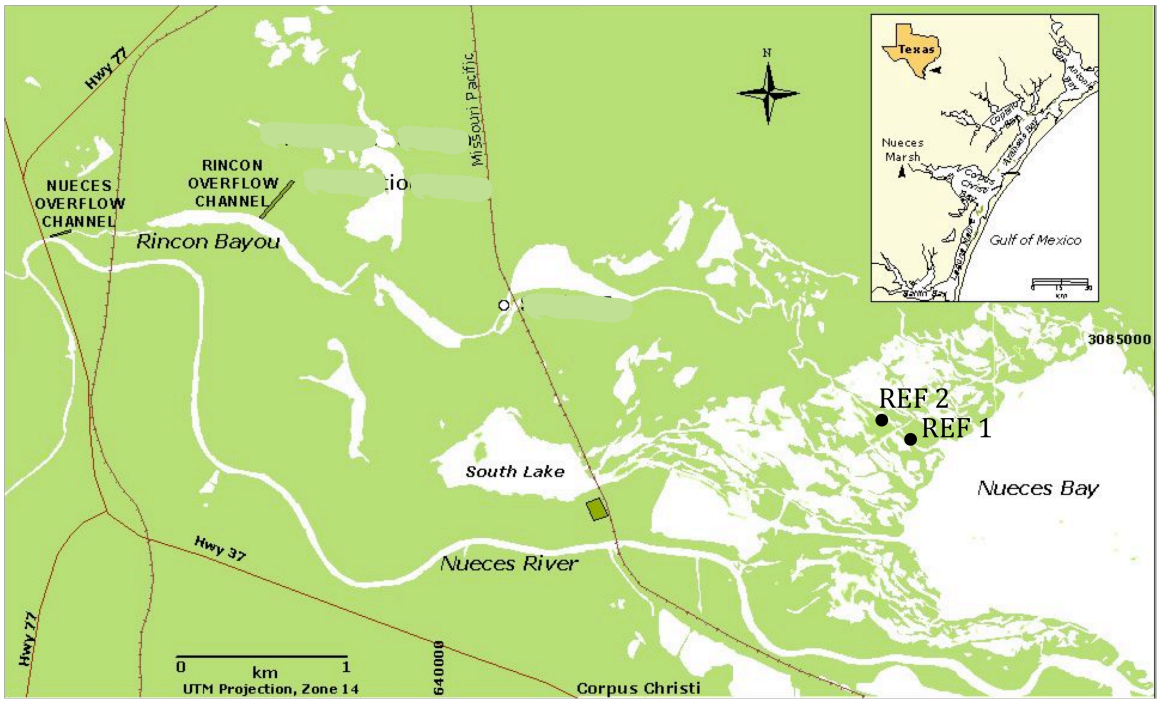

Figure 2.1: Map depicting sample sites within the Nueces Marsh. Isotope samples were collected from REF1 during the summer 2002-summer 2008 sample period. Samples were pooled from both REF1 and REF2 during 2009 and 2010.

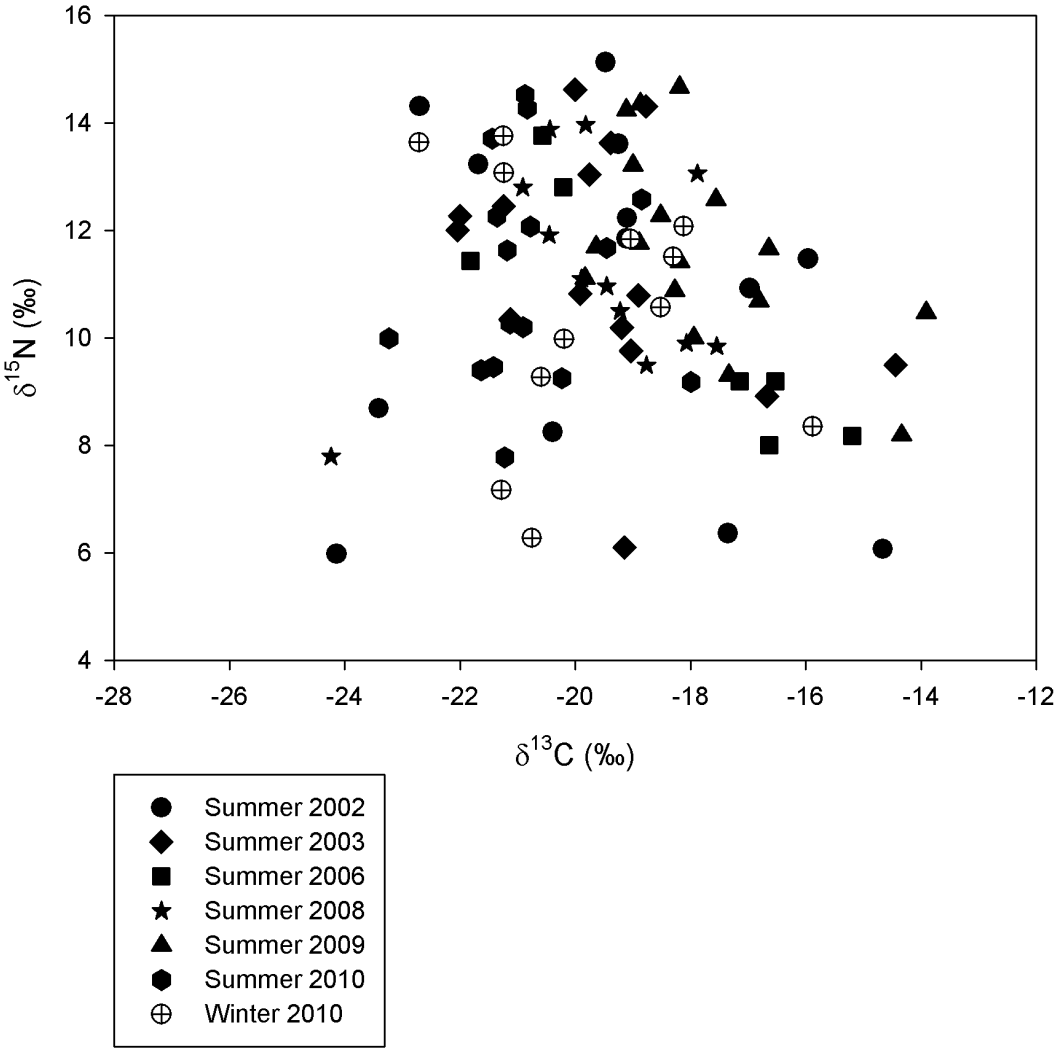

Figure 2.2: A biplot comparing $\delta^{15}N$:$\delta^{13}C$ values of consumer species collected in the Nueces Marsh during all six summer sampling seasons and winter 2010. Winter $\delta^{13}C$ values appear to be slightly to the depleted side of the spectrum presented by summer $\delta^{13}C$ values.

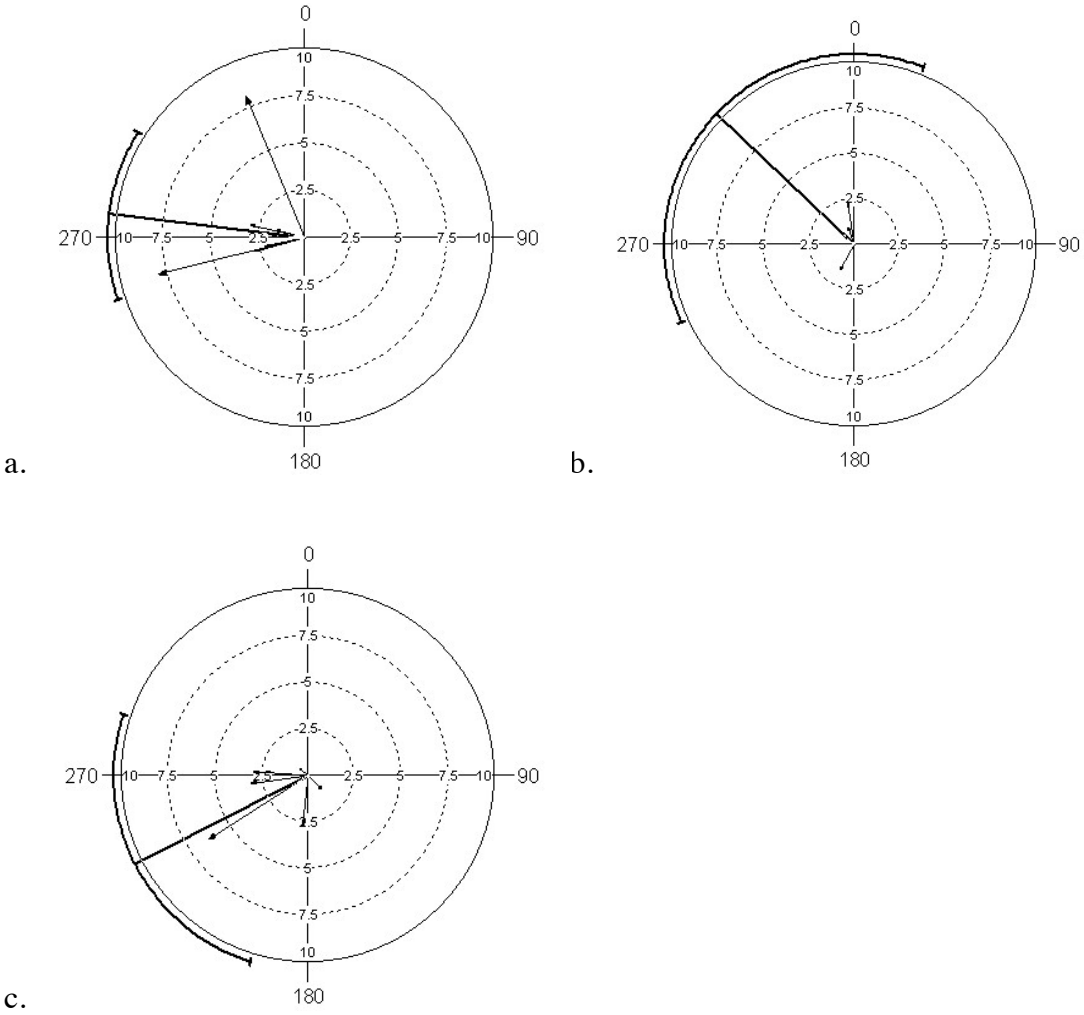

Figure 2.3: Vector plots for mean angle (θ) and magnitude (length *r*) of change in $\delta^{15}N$ and $\delta^{13}C$ among consumers in the Nueces Marsh. Top plot (a) depicts consumers becoming depleted in ^{13}C and slightly enriched in ^{15}N between summer 2009 and winter 2010;(b) depicts no net consumer shift between winter 2010 and summer 2010, and (c) depicts consumer depletion in both ^{13}C and ^{15}N between mean historic summers and winter 2010. Axes units are in ‰. The mean vector (μ) and the 95% confidence interval are represented by the solid straight line and the outer arc, respectively.

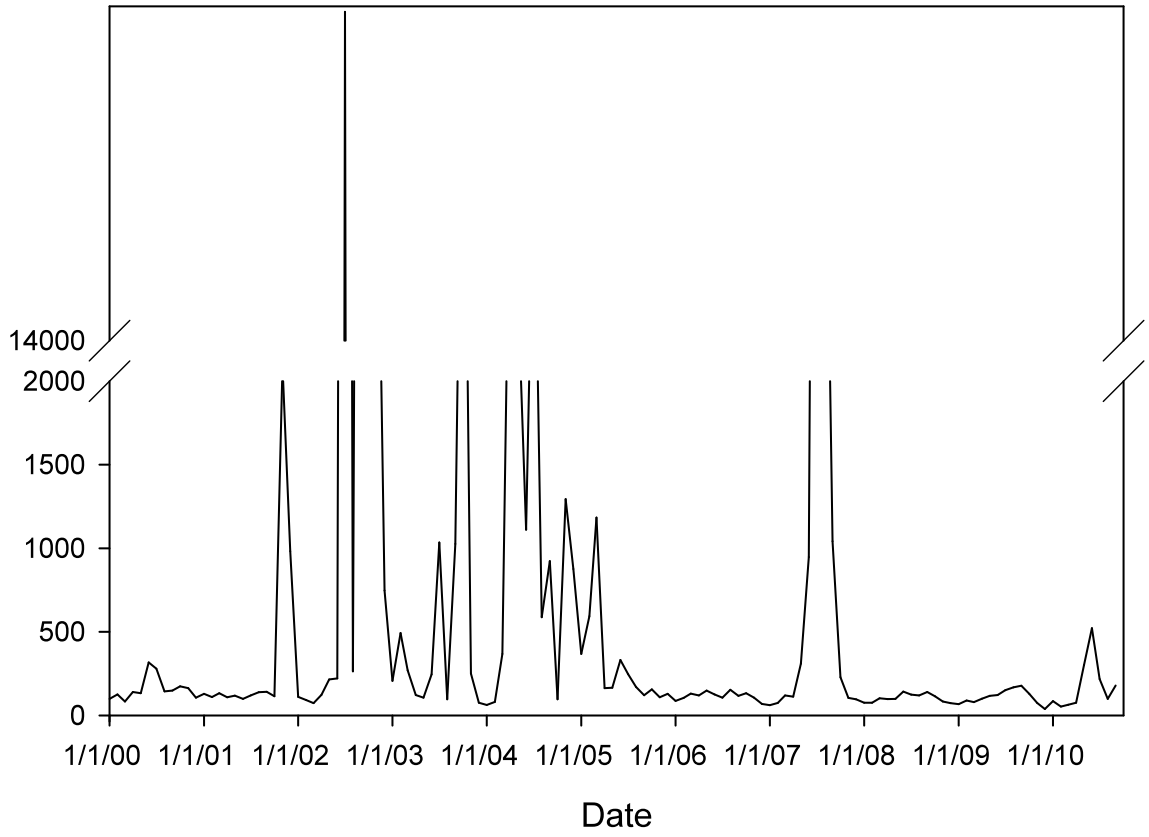

Figure 2.4: Discharge(cfs) from the Nueces River over the course of the sampling period (2000-2010). Data from USGS Surface Water Data for the USA.

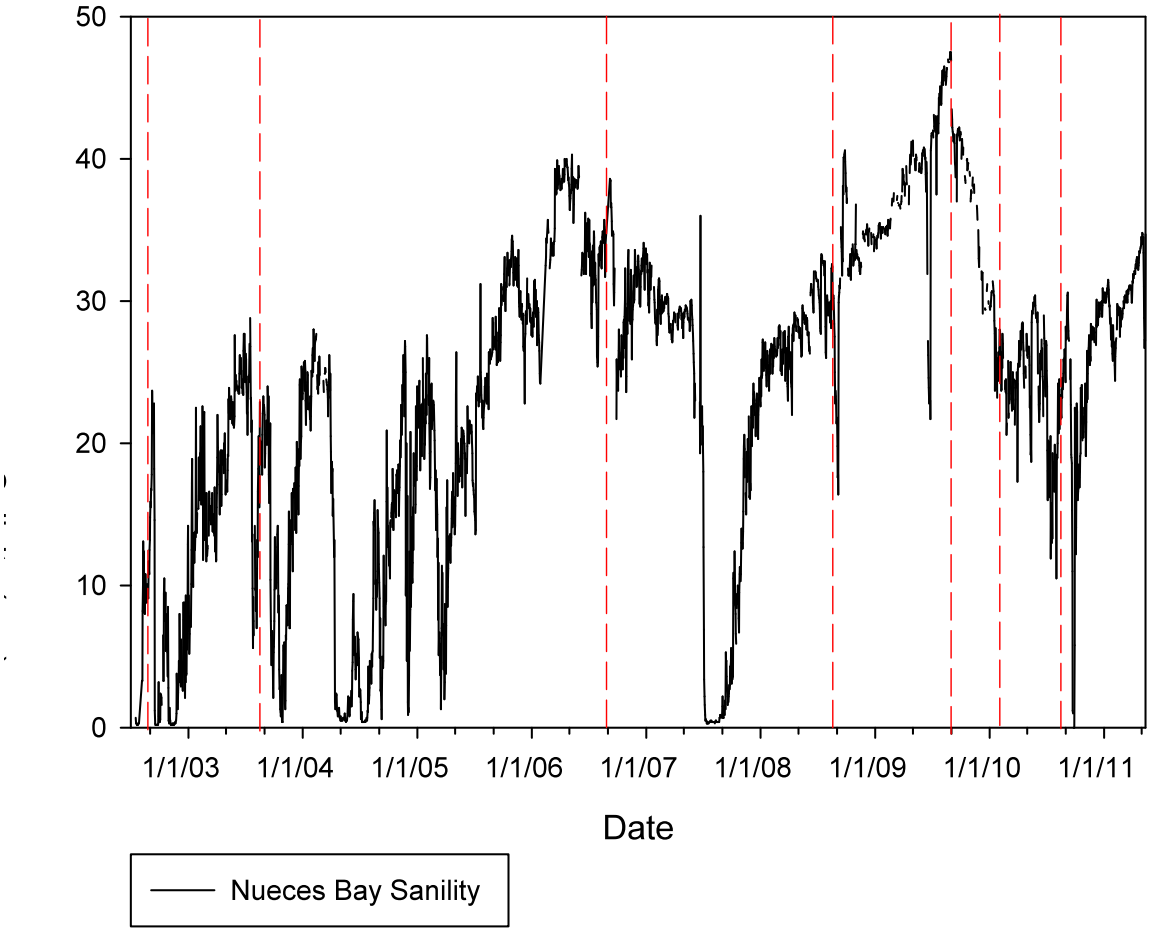

Figure 2.5: Salinity data from Nueces Bay (Texas Coastal Ocean Observation Network's SALT01 station) over the course of the study period. Dashed vertical lines represent when isotope samples were collected. Data courtesy of the Conrad Blucher Institute for Surveying and Science, Texas A&M-Corpus Christi

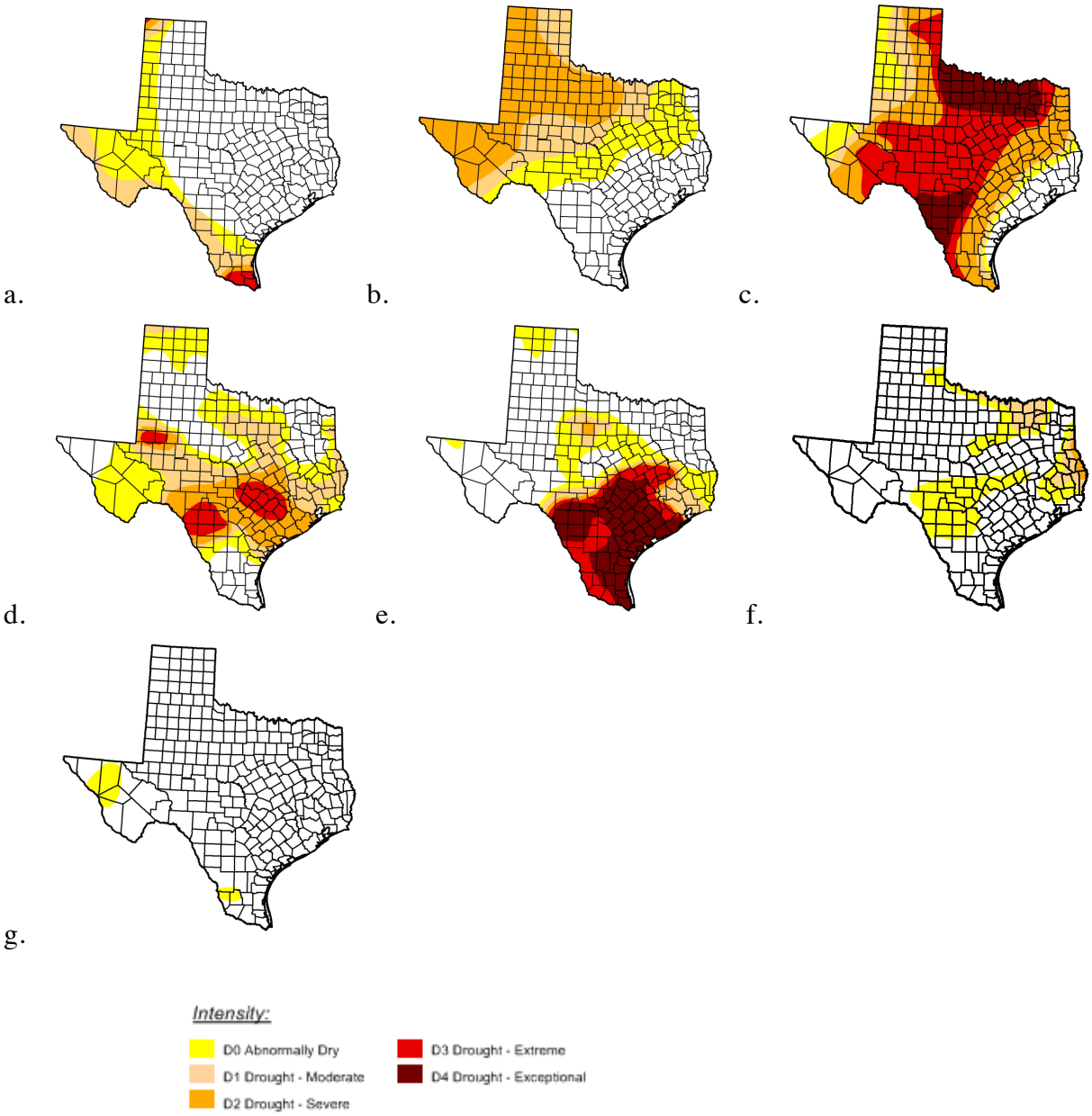

Figure 2.6: Map depicting drought conditions in the state of Texas during summers 2002 (a), 2003 (b), 2006 (c), 2008 (d), 2009 (e), 2010 (f), and winter 2010 (g). Data courtesy of the U.S. Drought Monitor (drought.unl.edu). Interannual variability in drought severity is high, with conditions ranging from normal (white) to exceptional (dark red). Temporal trends indicate that summers 2002, 2003, and 2010 were wetter, less intense drought years on the coastal bend. Winter 2010 likewise exhibited non-drought conditions. Summers 2006, 2008, and 2009 exhibited moderate to exceptional droughts.

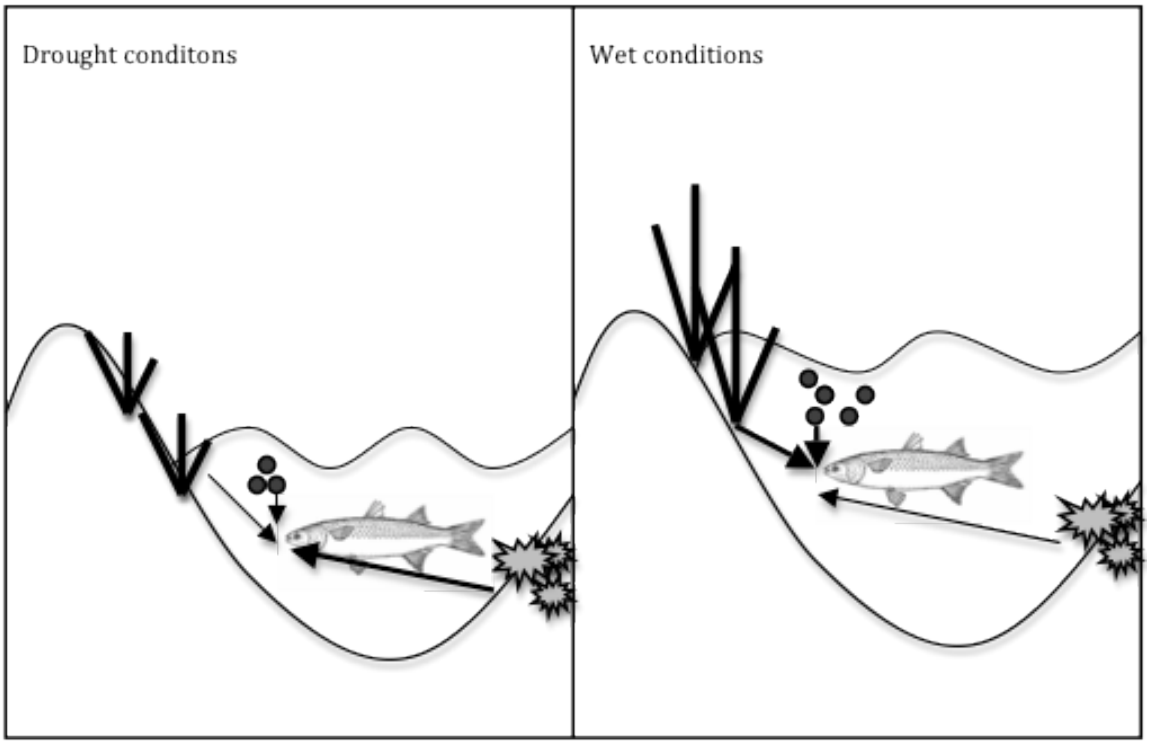

Figure 2.7: Conceptual diagram depicting shifts in ultimate carbon sources to consumers during wet and dry conditions. During droughts, water levels drop and salinity rises. These factors inhibit production by emergent plants and phytoplankton, making cyanobacterial carbon relatively more important. During wet years, high water levels and low salinities favor emergent plant and phytoplankton production, which relegates cyanobacterial carbon to a smaller portion of consumer diets.

Appendix: $\delta^{15}N/\delta^{13}C$ Values of Consumer Organisms Collected from the Nueces Marsh: 2002-2010

Species	Date Collected	Station	$\delta^{15}N$	$\delta^{13}C$
Achirus lineatus	08/05/2003	REF1	10.82	-19.91
Achirus lineatus	08/05/2003	WW2	13.01	-18.37
Achirus lineatus	08/11/2009	REF2	11.00	-18.32
Achirus lineatus	08/11/2009	REF2	10.79	-18.23
Achirus lineatus	08/10/2010	REF1	9.25	-21.53
Achirus lineatus	08/10/2010	REF1	11.29	-20.73
Anchoa mitchilli	06/13/2002	REF1	13.27	-21.68
Anchoa mitchilli	06/13/2002	REF1	13.18	-22.19
Anchoa mitchilli	06/13/2002	WW2	16.37	-21.19
Anchoa mitchilli	06/13/2002	WW2	16.83	-21.63
Anchoa mitchilli	08/05/2003	REF1	12.16	-21.95
Anchoa mitchilli	08/05/2003	REF1	12.38	-22.05
Anchoa mitchilli	08/05/2003	WW2	14.28	-21.41
Anchoa mitchilli	08/05/2003	WW2	14.48	-22.02
Anchoa mitchilli	06/15/2006	REF1	14.07	-20.58
Anchoa mitchilli	06/15/2006	REF1	13.46	-20.49
Anchoa mitchilli	06/15/2006	WW2	15.80	-17.68
Anchoa mitchilli	06/19/2008	REF1	12.18	-21.57
Anchoa mitchilli	06/19/2008	REF1	13.41	-20.26
Anchoa mitchilli	06/19/2008	WW2	16.44	-20.98
Anchoa mitchilli	06/19/2008	WW2	16.28	-21.25
Anchoa mitchilli	06/24/2009	REF1	14.54	-18,36
Anchoa mitchilli	06/24/2009	REF1	16.02	-17.45
Anchoa mitchilli	06/24/2009	REF1	14.77	-18.42
Anchoa mitchilli	06/24/2009	WW2	16.78	-19.10
Anchoa mitchilli	06/24/2009	WW2	9.99	-18.44
Anchoa mitchilli	06/24/2009	WW2	17.16	-19.42
Anchoa mitchilli	06/24/2009	WW2	15.30	-18.10
Anchoa mitchilli	08/11/2009	REF1	15.47	-19.41
Anchoa mitchilli	08/11/2009	REF1	13.63	-20.20
Anchoa mitchilli	08/11/2009	REF2	11.87	-20.38
Anchoa mitchilli	08/11/2009	REF2	13.36	-19.56
Anchoa mitchilli	08/11/2009	WW2	15.78	-19.45
Anchoa mitchilli	08/11/2009	WW2	17.65	-19.29
Anchoa mitchilli	08/11/2009	WW2	16.07	-18.87
Anchoa mitchilli	08/11/2009	WW3	15.27	-18.50
Anchoa mitchilli	08/11/2009	WW3	14.30	-18.60
Anchoa mitchilli	08/11/2009	WW4	14.63	-19.22
Anchoa mitchilli	08/11/2009	WW4	14.00	-19.44
Anchoa mitchilli	02/09/2010	REF1	15.20	-21.92
Anchoa mitchilli	02/09/2010	REF1	13.71	-21.97
Anchoa mitchilli	02/09/2010	REF2	12.59	-20.89

Anchoa mitchilli	02/09/2010	REF2	13.53	-20.21
Anchoa mitchilli	02/09/2010	WW2	11.35	-21.47
Anchoa mitchilli	02/09/2010	WW2	18.14	-20.20
Anchoa mitchilli	02/09/2010	WW3	10.89	-21.83
Anchoa mitchilli	02/09/2010	WW3	12.60	-21.12
Anchoa mitchilli	02/09/2010	WW3	11.31	-20.45
Anchoa mitchilli	02/09/2010	WW3	11.89	-20.89
Anchoa mitchilli	02/09/2010	WW4	12.94	-20.90
Anchoa mitchilli	02/09/2010	WW4	11.53	-21.59
Anchoa mitchilli	08/10/2010	REF1	12.04	-21.59
Anchoa mitchilli	08/10/2010	REF1	12.96	-22.41
Anchoa mitchilli	08/10/2010	REF2	12.09	-21.76
Anchoa mitchilli	08/10/2010	REF2	12.33	-22.08
Anchoa mitchilli	08/10/2010	WW2	14.66	-22.29
Anchoa mitchilli	08/10/2010	WW2	15.15	-21.81
Anchoa mitchilli	08/10/2010	WW3	14.86	-21.77
Anchoa mitchilli	08/10/2010	WW3	14.44	-22.16
Ariopsis felis	08/05/2003	REF1	13.68	-18.88
Ariopsis felis	08/05/2003	REF1	14.95	-18.66
Ariopsis felis	08/05/2003	WW2	16.98	-25.31
Ariopsis felis	06/19/2008	REF1	13.24	-21.12
Ariopsis felis	06/19/2008	REF1	14.53	-19.75
Ariopsis felis	06/24/2009	REF1	14.56	-19.12
Ariopsis felis	06/24/2009	REF1	14.00	-17.69
Ariopsis felis	06/24/2009	REF1	14.31	-19.40
Ariopsis felis	06/24/2009	REF1	14.43	-19.51
Ariopsis felis	08/11/2009	REF1	14.01	-18.95
Ariopsis felis	08/11/2009	REF1	14.85	-18.58
Ariopsis felis	03/11/2010	WW2	16.02	-16.80
Ariopsis felis	03/11/2010	WW2	16.75	-18.99
Ariopsis felis	08/10/2010	WW2	14.83	-20.43
Ariopsis felis	08/10/2010	WW2	14.00	-20.09
Ariopsis felis	08/10/2010	WW3	14.76	-20.26
Ariopsis felis	08/10/2010	WW3	14.98	-20.11
Bagre marinus	08/10/2010	REF1	14.27	-20.83
Bothus sp.	06/13/2002	REF1	12.01	-18.77
Bothus sp.	06/13/2002	REF1	12.46	-19.43
Brevoortia patronus	06/13/2002	REF1	10.31	-20.89
Brevoortia patronus	06/13/2002	REF1	--	-19.89
Brevoortia patronus	06/13/2002	WW2	13.78	-19.52
Brevoortia patronus	08/05/2003	REF1	9.92	-21.52
Brevoortia patronus	08/05/2003	REF1	14.02	-22.55
Brevoortia patronus	08/05/2003	WW2	8.12	-27.20

Brevoortia patronus	08/05/2003	WW2	10.45	-25.99
Brevoortia patronus	06/15/2006	REF1	13.21	-20.57
Brevoortia patronus	06/15/2006	REF1	12.39	-19.85
Brevoortia patronus	06/15/2006	WW2	14.08	-20.40
Brevoortia patronus	06/19/2008	REF1	11.91	-20.45
Brevoortia patronus	06/19/2008	REF1	10.99	-19.87
Brevoortia patronus	06/19/2008	WW2	15.32	-20.83
Brevoortia patronus	06/24/2009	REF1	9.62	-16.89
Brevoortia patronus	06/24/2009	REF1	13.85	-19.31
Brevoortia patronus	06/24/2009	REF1	11.81	-20.15
Brevoortia patronus	06/24/2009	REF1	11.76	-19.22
Brevoortia patronus	06/24/2009	WW3	13.94	-19.53
Brevoortia patronus	06/24/2009	WW3	13.52	-19.62
Brevoortia patronus	08/10/2010	REF1	13.49	-22.09
Brevoortia patronus	08/10/2010	REF1	14.04	-19.95
Brevoortia patronus	08/10/2010	REF2	13.51	-22.52
Brevoortia patronus	08/10/2010	REF2	13.81	-21.19
Brevoortia patronus	08/10/2010	WW2	13.82	-22.28
Brevoortia patronus	08/10/2010	WW2	14.73	-23.72
Brevoortia patronus	08/10/2010	WW3	14.41	-20.58
Brevoortia patronus	08/10/2010	WW3	12.92	-21.64
Callinectes sapidus	06/13/2002	REF1	6.19	-23.36
Callinectes sapidus	06/13/2002	REF1	5.76	-24.92
Callinectes sapidus	08/05/2003	REF1	10.28	-20.85
Callinectes	08/05/2003	REF1	10.39	-21.39

sapidus				
Callinectes sapidus	08/05/2003	WW2	10.94	-21.56
Callinectes sapidus	08/05/2003	WW2	11.41	-21.33
Callinectes sapidus	06/15/2006	REF1	11.40	-22.07
Callinectes sapidus	06/15/2006	REF1	11.47	-21.58
Callinectes sapidus	06/15/2006	WW2	11.88	-18.54
Callinectes sapidus	06/19/2008	REF1	10.20	-17.82
Callinectes sapidus	06/19/2008	REF1	9.61	-18.32
Callinectes sapidus	06/19/2008	REF1	9.15	-21.95
Callinectes sapidus	06/19/2008	REF1	10.41	-21.77
Callinectes sapidus	06/19/2008	WW2	12.47	-21.15
Callinectes sapidus	06/19/2008	WW2	12.23	-23.17
Callinectes sapidus	06/24/2009	REF1	11.81	-17.37
Callinectes sapidus	06/24/2009	REF1	17.51	-19.00
Callinectes sapidus	06/24/2009	WW2	12.35	-17.27
Callinectes sapidus	06/24/2009	WW2	14.47	-18.16
Callinectes sapidus	08/11/2009	WW3	16.38	-19.23
Callinectes sapidus	02/09/2010	REF1	9.37	-22.77
Callinectes sapidus	02/09/2010	REF2	6.24	-22.22
Callinectes sapidus	02/09/2010	WW2	14.28	-16.37
Callinectes sapidus	02/09/2010	WW2	13.43	-17.34
Callinectes sapidus	02/09/2010	WW3	11.08	-19.23
Callinectes sapidus	02/09/2010	WW3	10.52	-17.94
Callinectes sapidus	02/09/2010	WW4	11.92	-20.04
Callinectes sapidus	02/09/2010	WW4	11.75	-20.55

Callinectes sapidus	03/11/2010	REF2	7.43	-20.18
Callinectes sapidus	03/11/2010	REF2	5.64	-19.97
Callinectes sapidus	08/10/10	REF1	10.55	-22.41
Callinectes sapidus	08/10/10	REF1	10.28	-21.60
Callinectes sapidus	08/10/10	REF2	7.28	-21.67
Callinectes sapidus	08/10/10	REF2	11.51	-22.99
Callinectes sapidus	08/10/2010	WW2	12.21	-21.24
Callinectes sapidus	08/10/2010	WW2	10.88	-20.38
Callinectes sapidus	08/10/2010	WW3	13.61	-23.22
Callinectes sapidus	08/10/2010	WW3	10.69	-20.36
Citharichthys spilopterus	08/05/2003	REF1	12.27	-19.68
Citharichthys spilopterus	06/24/2009	REF1	12.28	-18.52
Citharichthys spilopterus	03/11/2010	REF1	11.84	-19.04
Citharichthys spilopterus	03/11/2010	WW3	14.89	-17.76
Citharichthys spilopterus	03/11/2010	WW3	14.78	-18.37
Citharichthys spilopterus	08/10/2010	REF1	9.18	-17.99
Cynoscion arenarius	06/13/2002	WW2	13.45	-17.48
Cynoscion arenarius	06/13/2002	WW2	15.05	-18.51
Cynoscion arenarius	06/24/2009	WW2	17.14	-18.27
Cynoscion arenarius	06/24/2009	WW2	16.53	-18.60
Cynoscion arenarius	08/10/2010	REF1	14.52	-20.87
Cynoscion arenarius	08/10/2010	WW3	15.49	-20.76
Cynoscion nebulosus	08/05/2003	REF1	12.86	-19.51
Cynoscion nebulosus	08/05/2003	REF1	13.22	-19.99
Cynoscion	08/05/2003	WW2	14.48	-20.71

nebulosus				
Cynoscion nebulosus	08/05/2003	WW2	15.32	-20.63
Cynoscion nebulosus	06/19/2008	REF1	12.69	-18.13
Cynoscion nebulosus	06/19/2008	REF1	13.42	-17.64
Cynoscion nebulosus	06/24/2009	REF1	13.48	-18.75
Cynoscion nebulosus	08/11/2009	REF1	11.66	-16.36
Cynoscion nebulosus	08/11/2009	WW4	13.97	-16.10
Cynoscion nebulosus	08/11/2009	WW4	15.33	-18.26
Cynoscion nebulosus	08/10/2010	REF1	10.96	-21.14
Cynoscion nebulosus	08/10/2010	REF1	12.29	-21.22
Cynoscion nebulosus	08/10/2010	WW2	13.33	-22.10
Cynoscion nebulosus	08/10/2010	WW2	13.66	-21.20
Cynoscion nebulosus	08/10/2010	WW3	14.29	-22.56
Cynoscion nebulosus	08/10/2010	WW3	12.99	-19.42
Cynoscion variegatus	06/13/2002	WW2	8.85	-14.92
Cynoscion variegatus	06/13/2002	WW2	6.74	-15.86
Cynoscion variegatus	06/24/2009	WW2	11.64	-16.41
Cynoscion variegatus	06/24/2009	WW2	11.09	-16.82
Cynoscion variegatus	06/24/2009	WW2	11.76	-15.45
Cynoscion variegatus	08/11/2009	WW2	13.83	-13.84
Cynoscion variegatus	08/11/2009	WW2	14.22	-12.18
Cynoscion variegatus	08/11/2009	WW2	14.01	-13.57
Cynoscion variegatus	02/09/2010	WW2	11.67	-16.79
Cynoscion variegatus	02/09/2010	WW3	10.43	-19.04
Cynoscion variegatus	02/09/2010	WW3	10.88	-17.71

Cynoscion variegatus	08/10/2010	WW3	8.50	-18.24
Cynoscion variegatus	08/10/2010	WW3	8.72	-15.84
Cyprinodon variegatus	06/13/2002	REF1	6.81	-17.04
Cyprinodon variegatus	06/13/2002	REF1	5.91	-17.66
Cyprinodon variegatus	08/11/2009	WW4	15.89	-19.10
Cyprinodon variegatus	08/11/2009	WW4	12.56	-16.71
Cyprinodon variegatus	02/09/2010	REF1	8.40	-15.65
Cyprinodon variegatus	02/09/2010	REF1	7.33	-15.67
Cyprinodon variegatus	02/09/2010	REF2	9.20	-17.91
Cyprinodon variegatus	02/09/2010	WW4	8.10	-16.77
Cyprinodon variegatus	02/09/2010	WW4	8.33	-19.18
Dasyatis sabina	08/10/2010	WW2	14.35	-17.91
Dorosoma cepedianum	06/24/2009	REF1	12.02	-19.27
Dorosoma cepedianum	06/24/2009	REF1	12.36	-20.33
Dorosoma cepedianum	06/24/2009	REF1	10.96	-18.96
Dorosoma cepedianum	06/24/2009	WW3	12.64	-20.44
Dorosoma cepedianum	06/24/2009	WW3	14.40	-19.80
Dorosoma cepedianum	08/11/2009	REF1	11.48	-20.00
Elops saurus	06/15/2006	WW2	14.96	-15.76
Elops saurus	06/15/2006	WW2	16.27	-13.95
Elops saurus	06/19/2008	REF1	10.50	-17.51
Elops saurus	06/19/2008	REF1	14.98	-20.03
Elops saurus	06/19/2008	WW2	14.78	-19.04
Elops saurus	06/19/2008	WW2	12.49	-18.35
Elops saurus	06/24/2009	WW3	16.14	-17.84
Elops saurus	06/24/2009	WW3	14.75	-16.71
Elops saurus	06/24/2009	WW3	14.73	-18.95
Elops saurus	06/24/2009	WW3	15.62	-18.39
Eucinostomus argenteus	06/24/2009	WW2	16.08	-18.77
Eucinostomus argenteus	08/11/2009	WW4	13.08	-16.20

Eucinostomus argenteus	08/11/2009	WW4	12.71	-15.94
Eucinostomus argenteus	08/10/2010	REF2	9.25	-20.23
Eucinostomus argenteus	08/10/2010	WW2	12.99	-22.77
Eucinostomus argenteus	08/10/2010	WW2	12.98	-21.56
Eucinostomus argenteus	08/10/2010	WW3	12.96	-20.68
Eucinostomus argenteus	08/10/2010	WW3	12.31	-21.24
Eucinostomus gula	08/11/2009	WW4	13.49	-18.21
Eucinostomus gula	08/11/2009	WW4	13.11	-17.19
Fundulus grandis	06/13/2002	WW2	13.95	-18.00
Fundulus grandis	06/15/2006	REF1	9.82	-17.32
Fundulus grandis	06/15/2006	REF1	8.56	-16.97
Fundulus grandis	06/24/2009	REF1	9.49	-18.34
Fundulus grandis	06/24/2009	REF1	9.62	-16.95
Fundulus grandis	06/24/2009	WW2	8.30	-15.65
Fundulus grandis	06/24/2009	WW2	12.24	-17.94
Fundulus grandis	06/24/2009	WW2	12.74	-17.64
Fundulus grandis	06/24/2009	WW2	14.01	-17.43
Fundulus grandis	08/11/2009	WW1	17.52	-16.94
Fundulus grandis	02/09/2010	WW2	15.05	-18.27
Fundulus grandis	02/09/2010	WW2	15.64	-18.13
Fundulus grandis	02/09/2010	WW4	11.61	-19.09
Fundulus grandis	02/09/2010	WW4	11.45	-17.48
Fundulus grandis	03/11/2010	REF1	9.14	-22.21
Fundulus grandis	03/11/2010	REF1	9.73	-21.17
Fundulus grandis	08/10/2010	WW2	9.52	-18.76
Fundulus pulvereus	06/13/2002	WW2	9.98	-16.68
Fundulus pulvereus	08/05/2003	REF1	11.18	-17.29
Fundulus similis	06/24/2009	REF1	9.26	-16.58
Fundulus similis	06/24/2009	REF1	9.92	-17.89
Fundulus similis	06/24/2009	REF1	8.70	-16.76
Fundulus similis	06/24/2009	REF1	8.85	-17.49
Fundulus similis	06/24/2009	WW2	14.44	-15.42
Fundulus similis	08/11/2009	WW3	14.61	-14.59
Fundulus similis	08/11/2009	WW3	15.30	-14.43
Fundulus similis	02/09/2010	REF2	10.47	-19.09
Fundulus similis	02/09/2010	REF2	10.60	-18.31
Fundulus similis	02/09/2010	WW2	13.08	-18.28
Fundulus similis	02/09/2010	WW3	13.98	-18.28
Fundulus similis	02/09/2010	WW3	16.09	-17.37

Fundulus similis	02/09/2010	WW3	14.77	-18,05
Fundulus similis	03/11/2010	WW4	10.74	-16.81
Fundulus similis	03/11/2010	WW4	11.15	-20.01
Fundulus similis	08/10/2010	WW3	12.93	-17.96
Fundulus similis	08/10/2010	WW3	12.21	-17.47
Gobioides bosc	06/24/2009	REF1	12.01	-18.97
Gobioides bosc	08/11/2009	REF2	10.64	-19.97
Gobioides bosc	08/11/2009	REF2	10.67	-20.54
Gobioides bosc	08/10/2010	REF1	5.43	-20.29
Gobioides bosc	08/10/2010	REF2	10.14	-22.14
Gobioides broussonnetii	08/05/2003	REF1	8.92	-16.67
Gobioides broussonnetii	06/24/2009	WW2	11.62	-19.32
Gobioides broussonnetii	06/24/2009	WW2	13.29	-21.15
Gobioides broussonnetii	06/24/2009	WW2	10.62	-17.29
Gobioides broussonnetii	06/24/2009	WW2	10.75	-18.95
Gobioides broussonnetii	03/11/2010	REF1	13.07	-21.24
Gobioides broussonnetii	08/10/2010	REF1	9.99	-23.23
Gobiosoma bosc	08/05/2003	REF1	10.69	-18.67
Gobiosoma bosc	08/05/2003	REF1	10.89	-19.13
Gobiosoma bosc	08/05/2003	WW2	13.93	-20.90
Gobiosoma bosc	08/05/2003	WW2	14.29	-21.74
Gobiosoma bosc	03/11/2010	WW3	16.18	-18.73
Gobiosoma bosc	03/11/2010	WW3	14.70	-18.27
Laconereis culveri	06/15/2006	REF1	8.94	-14.65
Laconereis culveri	08/05/2003	REF1	6.02	-19.44
Laconereis culveri	08/05/2003	REF1	6.19	-18.84
Laconereis culveri	08/05/2003	WW2	11.87	-18.80
Laconereis culveri	08/05/2003	WW2	12.15	-18.25
Laconereis culveri	06/15/2006	REF1	7.40	-17.16
Laconereis culveri	06/15/2006	WW2	12.44	-24.16
Lagodon rhomboides	06/13/2002	REF1	11.86	-18.74
Lagodon rhomboides	06/13/2002	REF1	11.85	-19.48
Lagodon	06/13/2002	WW2	15.65	-20.25

rhomboides				
Lagodon rhomboides	06/13/2002	WW2	16.86	-20.63
Lagodon rhomboides	06/15/2006	WW2	15.02	-16.91
Lagodon rhomboides	06/15/2006	WW2	13.72	-17.54
Lagodon rhomboides	06/19/2008	REF1	10.74	-19.50
Lagodon rhomboides	06/19/2008	REF1	11.46	-20.14
Lagodon rhomboides	06/19/2008	WW2	14.61	-21.46
Lagodon rhomboides	06/19/2008	WW2	15.78	-19.96
Lagodon rhomboides	06/24/2009	REF1	11.70	-18.87
Lagodon rhomboides	06/24/2009	REF1	12.20	-18.04
Lagodon rhomboides	06/24/2009	REF1	10.37	-17.62
Lagodon rhomboides	06/24/2009	WW3	16.09	-18.33
Lagodon rhomboides	06/24/2009	WW3	15.22	-17.85
Lagodon rhomboides	08/10/2010	REF2	14.36	-19.68
Lagodon rhomboides	08/10/2010	REF2	9.27	-22.19
Lagodon rhomboides	08/10/2010	REF2	9.64	-22.41
Lagodon rhomboides	08/10/2010	WW3	13.52	-19.02
Lagodon rhomboides	08/10/2010	WW3	13.94	-22.00
Leiostomus xanthurus	08/05/2003	REF1	11.50	-18.76
Leiostomus xanthurus	08/05/2003	REF1	15.77	-19.99
Leiostomus xanthurus	08/05/2003	WW2	14.32	-20.63
Leiostomus xanthurus	06/15/2006	WW2	14.30	-17.23
Leiostomus xanthurus	06/15/2006	WW2	15.17	-15.67
Leiostomus xanthurus	08/11/2009	WW3	15.09	-17.29
Leiostomus xanthurus	08/11/2009	WW3	17.26	-17.45

Leiostomus xanthurus	08/10/2010	REF1	13.43	-19.66
Leiostomus xanthurus	08/10/2010	REF2	11.97	-20.18
Leiostomus xanthurus	08/10/2010	REF2	9.62	-18.51
Leiostomus xanthurus	08/10/2010	WW2	14.05	-20.34
Leiostomus xanthurus	08/10/2010	WW2	13.37	-21.04
Leiostomus xanthurus	08/10/2010	WW3	12.29	-20.27
Leiostomus xanthurus	08/10/2010	WW3	12.38	-18.08
Leiostomus xanthurus	08/10/2010	WW3	16.86	-17.25
Lolliguncula brevis	06/13/2002	REF1	15.70	-22.70
Lolliguncula brevis	06/13/2002	WW2	15.81	-21.48
Lolliguncula brevis	06/13/2002	WW2	16.37	-22.16
Marphysa sanguinea	06/15/2006	REF1	7.77	-16.51
Marphysa sanguinea	06/15/2006	REF1	8.23	-16.77
Menidia peninsulae	06/13/2002	REF1	13.78	-19.83
Menidia peninsulae	06/13/2002	REF1	13.43	-18.68
Menidia peninsulae	06/13/2002	WW2	12.42	-18.45
Menidia peninsulae	06/13/2002	WW2	-22.33	15.45
Menidia peninsulae	08/05/2003	REF1	12.33	-21.00
Menidia peninsulae	08/05/2003	REF1	12.56	-21.48
Menidia peninsulae	08/05/2003	WW2	13.96	-18.05
Menidia peninsulae	06/15/2006	WW2	12.27	-16.00
Menidia peninsulae	06/24/2009	REF1	11.29	-15.29
Menidia peninsulae	06/24/2009	REF1	12.00	-17.79
Menidia peninsulae	06/24/2009	REF1	11.68	-16.90
Menidia	06/24/2009	WW2	12.68	-16.39

peninsulae				
Menidia peninsulae	06/24/2009	WW2	16.02	-18.45
Menidia peninsulae	08/11/2009	WW4	14.48	-18.32
Menidia peninsulae	08/11/2009	WW4	14.29	-18.65
Menidia peninsulae	02/09/2010	REF1	11.34	-18.62
Menidia peninsulae	02/09/2010	REF1	11.62	-18.22
Menidia peninsulae	02/09/2010	REF2	12.72	-19.18
Menidia peninsulae	02/09/2010	WW4	13.94	-17.74
Menidia peninsulae	02/09/2010	WW4	15.30	-18.37
Menidia peninsulae	03/11/2010	REF2	12.54	-17.33
Menidia peninsulae	03/11/2010	REF2	12.16	-17.25
Menidia peninsulae	08/10/2010	REF1	10.85	-20.61
Menidia peninsulae	08/10/2010	REF1	13.28	-16.98
Menidia peninsulae	08/10/2010	REF2	13.86	-18.65
Menidia peninsulae	08/10/2010	REF2	12.32	-18.97
Menidia peninsulae	08/10/2010	WW3	12.70	-21.51
Menidia peninsulae	08/10/2010	WW3	11.60	-18.59
Micropogonias undulatus	06/13/2002	WW2	18.56	-18.54
Micropogonias undulatus	06/13/2002	WW2	17.30	-18.59
Micropogonias undulatus	06/19/2008	REF1	12.86	-19.74
Micropogonias undulatus	06/19/2008	REF1	15.06	-20.05
Micropogonias undulatus	06/19/2008	WW2	15.85	-19.44
Micropogonias undulatus	06/24/2009	REF1	13.51	-19.69
Micropogonias undulatus	06/24/2009	REF1	12.93	-19.45
Micropogonias undulatus	06/24/2009	WW3	14.43	-16.58

Micropogonias undulatus	06/24/2009	WW3	13.04	-18.40
Micropogonias undulatus	08/11/2009	REF1	14.29	-19.09
Micropogonias undulatus	08/11/2009	REF1	12.09	-17.79
Micropogonias undulatus	08/10/2010	REF1	12.11	-21.11
Micropogonias undulatus	08/10/2010	REF1	12.02	-20.45
Micropogonias undulatus	08/10/2010	WW2	15.27	-20.48
Micropogonias undulatus	08/10/2010	WW3	15.77	-20.47
Micropogonias undulatus	08/10/2010	WW3	--	-20.32
Mugil cephalus	06/13/2002	REF1	8.21	-14.57
Mugil cephalus	06/13/2002	REF1	14.74	-17.36
Mugil cephalus	06/13/2002	WW2	12.08	-15.89
Mugil cephalus	06/13/2002	WW2	9.54	-14.93
Mugil cephalus	08/05/2003	REF1	8.50	-13.17
Mugil cephalus	08/05/2003	REF1	10.47	-18.30
Mugil cephalus	08/05/2003	REF1	9.77	-15.77
Mugil cephalus	08/05/2003	WW2	7.49	-16.13
Mugil cephalus	08/05/2003	WW2	9.73	-17.66
Mugil cephalus	08/05/2003	WW2	9.97	-16.31
Mugil cephalus	08/05/2003	WW2	10.40	-17.67
Mugil cephalus	06/15/2006	REF1	6.34	-13.94
Mugil cephalus	06/15/2006	REF1	9.31	-14.94
Mugil cephalus	06/15/2006	WW2	13.11	-15.86
Mugil cephalus	06/15/2006	WW2	11.93	-14.82
Mugil cephalus	06/19/2008	REF1	10.30	-17.73
Mugil cephalus	06/19/2008	REF1	9.37	-17.36
Mugil cephalus	06/19/2008	WW2	11.74	-16.70
Mugil cephalus	06/19/2008	WW2	10.90	-17.02
Mugil cephalus	06/24/2009	REF1	8.46	-14.36
Mugil cephalus	06/24/2009	REF1	8.51	-14.29
Mugil cephalus	06/24/2009	WW3	14.47	-17.08
Mugil cephalus	06/24/2009	WW3	13.93	-18.47
Mugil cephalus	08/11/2009	REF2	7.60	--
Mugil cephalus	08/11/2009	WW2	14.61	-12.89
Mugil cephalus	08/11/2009	WW2	13.94	-13.81
Mugil cephalus	08/11/2009	WW2	9.64	-14.73
Mugil cephalus	08/11/2009	WW2	11.43	-14.55
Mugil cephalus	08/11/2009	WW3	14.26	-12.45
Mugil cephalus	08/11/2009	WW3	11.90	-12.22
Mugil cephalus	08/11/2009	WW3	12.76	-16.13
Mugil cephalus	08/11/2009	WW3	11.59	-15.14
Mugil cephalus	02/09/2010	REF2	7.41	-19.79

Mugil cephalus	02/09/2010	REF2	6.96	-19.73
Mugil cephalus	02/09/2010	WW4	7.73	-18.36
Mugil cephalus	02/09/2010	WW4	8.82	-19.20
Mugil cephalus	03/11/2010	REF1	5.75	-22.54
Mugil cephalus	03/11/2010	REF1	4.99	-20.95
Mugil cephalus	03/11/2010	WW2	7.12	-17.87
Mugil cephalus	03/11/2010	WW2	9.07	-23.79
Mugil cephalus	03/11/2010	WW3	7.99	-18.97
Mugil cephalus	03/11/2010	WW3	7.85	-19.09
Mugil cephalus	08/10/2010	REF2	6.38	-20.12
Mugil cephalus	08/10/2010	WW2	10.46	-19.49
Mugil cephalus	08/10/2010	WW2	9.95	-20.44
Mugil cephalus	08/10/2010	WW3	9.59	-13.61
Mugil cephalus	08/10/2010	WW3	10.12	-18.69
Opsanus beta	06/13/2002	REF1	8.69	-18.99
Palaemonetes sp.	08/05/2003	REF1	10.04	-19.10
Palaemonetes sp.	08/05/2003	REF1	10.33	-19.28
Palaemonetes sp.	06/15/2006	REF1	9.09	-16.77
Palaemonetes sp.	06/19/2008	REF1	6.15	-12.27
Palaemonetes sp.	06/19/2008	REF1	10.04	-19.65
Palaemonetes sp.	06/19/2008	WW2	11.28	-19.76
Palaemonetes sp.	06/19/2008	WW2	13.02	-18.62
Palaemonetes sp.	06/24/2009	REF1	10.02	-16.62
Palaemonetes sp.	06/24/2009	REF1	11.61	-17.51
Palaemonetes sp.	06/24/2009	REF1	9.77	-16.30
Palaemonetes sp.	02/09/2010	REF1	10.92	-17.81
Palaemonetes sp.	02/09/2010	REF1	7.74	-20.15
Palaemonetes sp.	02/09/2010	REF2	11.70	-17.06
Palaemonetes sp.	02/09/2010	REF2	11.92	-19.05
Palaemonetes sp.	02/09/2010	WW2	13.96	-17.42
Palaemonetes sp.	02/09/2010	WW2	15.28	-17.85
Palaemonetes sp.	02/09/2010	WW3	13.14	-18.10
Palaemonetes sp.	02/09/2010	WW3	14.80	-19.19
Palaemonetes sp.	02/09/2010	WW4	11.22	-17.25
Palaemonetes sp.	02/09/2010	WW4	11.60	-17.85
Paralichthys lethostigma	06/24/2009	REF1	14.02	-17.65
Penaeid shrimp	06/13/2002	REF1	6.73	-14.56
Penaeid shrimp	06/13/2002	REF1	5.41	-14.77
Penaeid shrimp	06/13/2002	WW2	12.90	-19.56
Penaeid shrimp	06/13/2002	WW2	13.80	-21.43
Penaeid shrimp	08/05/2003	REF1	9.57	-19.35
Penaeid shrimp	08/05/2003	REF1	10.33	-19.19
Penaeid shrimp	08/05/2003	REF1	9.51	-18.11
Penaeid shrimp	08/05/2003	REF1	10.00	-19.49
Penaeid shrimp	08/05/2003	WW2	10.71	-19.83
Penaeid shrimp	08/05/2003	WW2	13.69	-18.90
Penaeid shrimp	06/15/2006	REF1	11.74	-18.15

Penaeid shrimp	06/15/2006	REF1	8.32	-16.09
Penaeid shrimp	06/15/2006	REF1	9.12	-16.99
Penaeid shrimp	06/15/2006	REF1	7.60	-14.91
Penaeid shrimp	06/15/2006	WW2	10.23	-16.88
Penaeid shrimp	06/15/2006	WW2	12.31	-16.22
Penaeid shrimp	06/15/2006	WW2	13.33	-15.90
Penaeid shrimp	06/19/2008	REF1	9.81	-18.22
Penaeid shrimp	06/19/2008	REF1	9.17	-19.31
Penaeid shrimp	06/19/2008	WW2	11.76	-19.59
Penaeid shrimp	06/19/2008	WW2	13.88	-19.31
Penaeid shrimp	06/24/2009	REF1	11.28	-18.90
Penaeid shrimp	06/24/2009	REF1	14.93	-18.70
Penaeid shrimp	06/24/2009	REF1	8.33	-17.55
Penaeid shrimp	06/24/2009	REF1	8.20	-17.54
Penaeid shrimp	06/24/2009	WW2	12.36	-17.45
Penaeid shrimp	06/24/2009	WW2	15.79	-17.94
Penaeid shrimp	06/24/2009	WW2	13.67	-17.54
Penaeid shrimp	06/24/2009	WW2	15.02	-18.33
Penaeid shrimp	08/11/2009	REF1	9.97	-17.61
Penaeid shrimp	08/11/2009	REF1	10.14	-18.47
Penaeid shrimp	08/11/2009	REF2	8.56	-16.95
Penaeid shrimp	08/11/2009	REF2	8.58	-17.80
Penaeid shrimp	08/11/2009	WW2	13.29	-17.75
Penaeid shrimp	08/11/2009	WW2	12.48	-18.17
Penaeid shrimp	08/11/2009	WW3	10.45	-16.67
Penaeid shrimp	08/11/2009	WW3	12.98	-18.05
Penaeid shrimp	08/11/2009	WW3	10.36	-16.00
Penaeid shrimp	08/11/2009	WW4	11.36	-16.03
Penaeid shrimp	08/11/2009	WW4	8.77	-17.20
Penaeid shrimp	03/11/2010	REF1	7.62	-21.33
Penaeid shrimp	03/11/2010	REF1	10.92	-19.84
Penaeid shrimp	08/10/2010	REF1	13.21	-22.42
Penaeid shrimp	08/10/2010	REF1	7.29	-21.22
Penaeid shrimp	08/10/2010	REF1	11.82	-20.41
Penaeid shrimp	08/10/2010	REF1	8.48	-19.53
Penaeid shrimp	08/10/2010	WW2	12.29	-20.51
Penaeid shrimp	08/10/2010	WW3	12.75	-21.17
Penaeid shrimp	08/10/2010	WW3	9.85	-21.25
Peprilus paru	06/24/2009	REF1	16.09	-19.75
Peprilus paru	06/24/2009	REF1	15.80	-20.07
Peprilus paru	06/24/2009	REF1	14.78	-19.05
Pogonias cromis	06/19/2008	REF1	10.45	-18.34
Pogonias cromis	06/19/2008	WW2	11.12	-19.80
Pogonias cromis	06/24/2009	REF1	10.69	-15.41
Rangia sp.	06/15/2006	WW2	11.11	-18.82
Rangia sp.	06/19/2008	REF1	7.88	-24.42
Rangia sp.	06/19/2008	REF1	7.70	-24.05
Rangia sp.	06/24/2009	REF1	8.23	-11.93
Rangia sp.	06/24/2009	REF1	7.99	-13.41

Rangia sp.	06/24/2009	REF1	9.25	-18.77
Rangia sp.	02/09/2010	WW3	10.07	-17.75
Rangia sp.	02/09/2010	WW3	10.99	-18.71
Rangia sp.	02/09/2010	WW4	9.86	--
Rangia sp.	02/09/2010	WW4	9.72	-20.05
Rangia sp.	02/09/2010	WW4	9.37	-19.62
Rangia sp.	02/09/2010	WW4	8.58	-21.62
Rangia sp.	03/11/2010	REF1	1.84	-11.02
Sciaenops ocellatus	02/09/2010	REF1	12.24	-17.33
Sciaenops ocellatus	02/09/2010	REF1	10.55	-17.80
Sciaenops ocellatus	02/09/2010	REF2	12.35	-19.72
Sciaenops ocellatus	02/09/2010	REF2	10.04	-17.61
Sciaenops ocellatus	02/09/2010	WW2	17.29	-16.39
Sciaenops ocellatus	02/09/2010	WW2	18.76	-15.96
Sciaenops ocellatus	02/09/2010	WW3	18.86	-16.49
Sciaenops ocellatus	02/09/2010	WW3	14.16	-18.11
Sciaenops ocellatus	03/11/2010	REF1	12.37	-19.04
Scianops ocellatus	02/09/2010	WW4	13.71	-19.22
Scianops ocellatus	02/09/2010	WW4	12.45	-19.89
Scianops ocellatus	03/11/2010	WW4	12.57	-19.09
Strongylura marina	06/13/2002	REF1	12.59	-18.68
Strongylura marina	06/13/2002	REF1	17.67	-20.25

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